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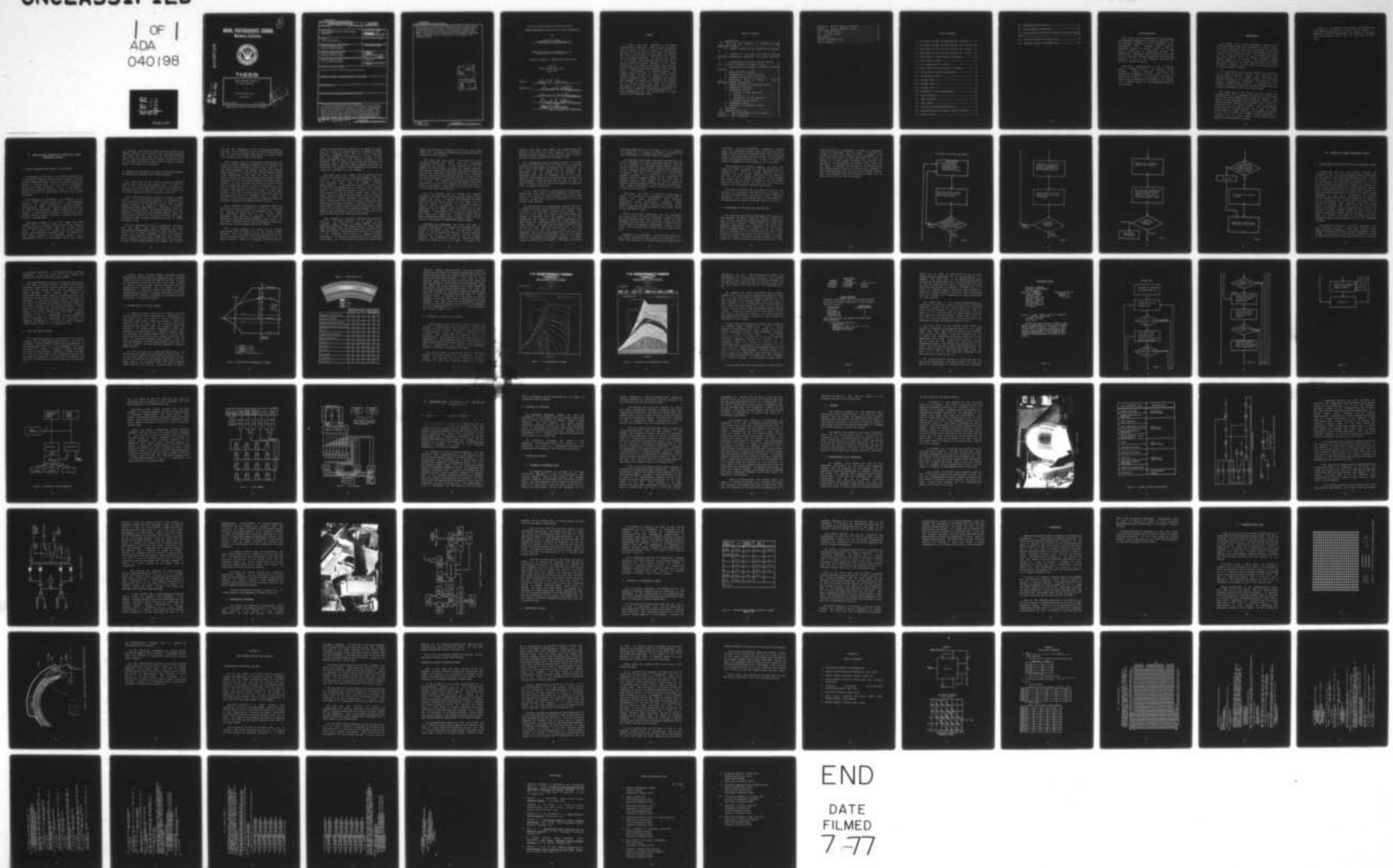

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NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

ENERGY MANAGEMENT DISPLAY FOR
AIR COMBAT MANEUVERING

by

Stuart Robinson Powrie

March 1977

Thesis Advisor: D. M. Layton

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUC BEFORE COMPLE
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NU.
6 4. TITLE (and Subtitle) ENERGY MANAGEMENT DISPLAY FOR AIR COMBAT MANEUVERING.		9 5. TYPE OF REPORT & PERIOD COVERED Master's Thesis, [redacted]
		6. PERFORMING ORG. REPORT NUMBER
10 7. AUTHOR(s) Stuart Robinson/Powrie		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		11 12. REPORT DATE Mar[redacted]977
		13. NUMBER OF PAGES 89 12 9Øp.
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Naval Postgraduate School Monterey, California 93940		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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ENERGY MANAGEMENT DISPLAY FOR AIR COMBAT MANEUVERING

by

Stuart R. Powrie
Lieutenant, United States Navy
B. S., United States Naval Academy 1970

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL

March 1977

Author: Stuart R. Powrie

Approved by: Donald M. Layton
Thesis Advisor

Lewis E. Waldeisen
Second Reader

Daniel J. Collins
Chairman, Department of Aeronautics

Robert R. Fossum
Dean of Science and Engineering

ABSTRACT

A skill and task analysis of air combat maneuvering was performed. This analysis indicated that a device to aid the pilot to maneuver the aircraft to its aerodynamic limits might be useful, but such a device might be ineffective due to a high level of sensory saturation. The concept for design of the project was predicated upon projected use of future displays for fighter aircraft in air combat maneuvering, pilot training and flight safety aspects. The test energy maneuverability display was designed using a microprocessor for dedicated control. The display format was based on color coding various specific power regions and presenting them in the pilot's peripheral vision. An experiment was designed and executed to determine if the pilot could respond to the specific power color codes and maintain performance of critical pilot tasks. An analysis of test variance indicated no significant degradation of pilot performance with the introduction of color coding to the peripheral vision.

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ACKNOWLEDGEMENTS

The entire staff of technicians of the Department of Aeronautics provided both technical assistance and the materials necessary to the completion of the experimental phase. Commander David Caswell's assistance during the initial phases of the mock cockpit construction was especially valuable and appreciated. Lieutenants Duane Englehardt, John Casko and Lewis McIntyre provided suggestions that aided the solution of many of the electronic problems that developed during the project.

Particular acknowledgement is due to Captain Clyde H. Tuomela, Director of Aviation Safety Programs. Captain Tuomela's criticisms and suggestions throughout the project aided greatly in maintaining continuity of the thesis. Additionally, Captain Tuomela permitted the students of his command to be used as subjects for the experimental phase of this project.

I. INTRODUCTION

The design of an energy management display for air combat maneuvering (ACM) was approached in three phases. The first phase was a skill and task analysis of the pilot of a fighter aircraft in air combat maneuvering based upon a typical combat mission scenario. This analysis emphasized the near critical levels of sensory saturation during various phases of the scenario. This analysis, combined with consideration of the flying characteristics of future generation fighters, clearly displayed the desirability of an energy management display.

The second phase was the actual design and construction of an energy management display. The complexity and understandability of the display design were based upon criteria determined from the skill and task analysis. Final display implementation included a microprocessor for dedicated control, a minimum of peripheral circuit logic and an easily interpreted color array based display.

The third phase of the project was the design and implementation of an experiment to determine the efficiency with which a human operator might employ the display. The purpose of this experiment was to determine if the use of an energy management display of this nature would detract so seriously from the pilot's primary task of maintaining visual sight of the enemy aircraft as to make its value questionable in a combat situation. The experiment resulted in the use of attack and fighter pilots performing a tracking task in a mock cockpit while interpreting the proposed energy management display.

Based on the results of this project, conclusions were made regarding the viability of such an energy display. A comparison was also made between this display and one being built and tested by a joint Navy and Air Force research team.

II. SKILL AND TASK ANALYSIS OF A TYPICAL AIR COMBAT MANEUVERING SCENARIO

A. MISSION OBJECTIVES AND SCENARIO TO BE ANALYZED

The objective of the pilot in air combat maneuvering is to successfully engage an enemy aircraft, maneuver to within a lethal weapon deployment envelope and fire the appropriate weapon to achieve a kill. Once involved in an engagement, the pilot's minimum performance must be to recognize a deteriorating tactical situation before it has become so adverse that he may no longer escape without being overly vulnerable.

The engagements of the scenario are conducted by F-4 aircraft against the MIG series aircraft. The engagements occur over the enemy's homeland in a dense electronic countermeasures (ECM), anti aircraft (AAA) and surface to air (SAM) threat environment. Enemy aircraft have the full benefit of local ground controlled intercepts (GCI), while friendly aircraft control is limited to a control station in excess of 100 miles away.

The scenario consists of two F-4's which have been launched from an aircraft carrier and have been tasked as flack suppressors and fighter cover for a large strike group. Both aircraft are leading the strike group on target, each carrying six 500-pound bombs in addition to four Sparrow missiles, four Sidewinder missiles and a centerline fuel tank. The controlling agency has advised

the aircraft that there are enemy aircraft airborne in the immediate vicinity of the target. The strike group approach has caused all local SAM, AAA and ECM sites to become active. Just following evasive maneuvers to avoid being hit by two SAM's, the lead F-4 pilot sights two shiney aircraft which do not appear to be friendly.

B. ANALYSIS OF THE TASKS OF THE PILOT OF THE LEAD AIRCRAFT IN SUCCESSFULLY COMPLETING THE STATED OBJECTIVE

The first task of the pilot is to gain and maintain visual contact with the enemy aircraft (Fig. 1, block A). This is the single most important aspect in prosecuting a successful air-to-air engagement. A very high portion of his visual capabilities must be devoted to this end.

Key in the pilot's ability to gain and maintain visual contact is his visual search technique. His probability of early detection is greatly increased if he knows in what general direction he should be looking. The friendly controlling agency might provide an approximate vector or sector in which to search. The onboard radar may be of some assistance. Perhaps the radar intercept officer (RIO) has visual contact and can talk the pilot's eyes onto the enemy. A wingman or other friendly aircraft may be able to narrow the search field.

The pilot must know for what he is searching. He should know the shape, size, color, performance and other distinguishing characteristics of the enemy aircraft. He should also be highly cognizant of what are the general tactics of the enemy and how the enemy has been trained. While attempting to gain sight of the enemy, the pilot must be aware of the continued SAM and AAA threat, and include

his own rear hemisphere as well as that of his wingman in his scan. At this critical stage, the pilot's eyes and mind must be out of the cockpit correlating all possible inputs in an attempt to gain sight of the enemy.

Once gaining sight of the possible enemy aircraft, the pilot must make an immediate evaluation of the situation and decide what course of action to follow (Fig. 1,block B). He must first determine if the sighted aircraft are possibly enemy aircraft or if they are just another forward segment of the strike group. If he feels that they are perhaps enemy aircraft, he must then evaluate their possible threat to himself or the strike group considering his basic mission tasking. He must consider his current fuel state. There must be enough fuel onboard to enter an engagement and then get to a tanker aircraft or return to the ship. Running out of fuel is the same as a kill for the enemy. If many enemy aircraft have been reported airborne and he has seen only one, unless that one is an immediate threat he would be prudent to wait several seconds before commiting himself in an effort to detect the presence of other aircraft.

After deciding to investigate the sighted aircraft, the pilot should initiate a maneuver to a position of advantage for positive identification and engagement (Fig. 2, block C). Maintaining visual sight of the probable enemy throughout this maneuver is mandatory. The enemy is probably at the pilot's visual detection range limit. If the pilot takes his eyes off of the opposing aircraft only momentarily, he will probably lose visual contact.

This initial maneuver will depend on the pilot's coordination with his wingman and on the relative enemy position. The pilot should maneuver the aircraft with the idea of achieving as quick a kill as possible, if it is an enemy aircraft. During the maneuver he must inform his

wingman of his intentions, insure that the wingman has sight also and inform the strike group of the presence of enemy aircraft. A frequency shift from the strike frequency, which the wingman must acknowledge, may be made. The SAM and AAA possibility may not be ignored, although in the immediate area of enemy aircraft these will probably be a diminished threat. The pilot must accomplish these tasks as efficiently as possible while maneuvering the aircraft as nearly as he possibly can to its optimum.

The pilot must also insure that all switches in the aircraft are properly set to enter the engagement (Fig. 2, block D). He must jettison the bombs and should jettison the centerline fuel tank to improve aircraft maneuverability. If the bombs are carried on stations 1 and 9, they may be jettisoned with the 'external tanks jettison switch.' If the bombs are carried on stations 2 and 8, they can be bombed off, but the triple ejector rack (TER) and bombs can not be selectively jettisoned. The pilot must be very careful to observe airspeed, acceleration and dive angle restrictions which vary according to bomb fuzing when jettisoning the bombs by bombing. Exceeding these limits could result in bomb-to-bomb collisions and detonation close enough to the aircraft to do significant damage. If he were working near any friendly ground forces, he would have to be more selective where the bombs were jettisoned.

Four switches are required to jettison the centerline fuel tank. Of these switches, all are common to the checklist which applies to normal bombing with one significant exception. The weapons switch is "CONV ON/NUC OFF" for bombing, while for jettisoning the centerline it is "CONV OFF/ NUC ON". Overlooking this switch in the pressure of the situation would result in degraded aircraft performance. In addition to these switches, the centerline tank should not be jettisoned when partially filled, when

faster than 425 knots or between 375 and 425 knots below 15000 feet. Jettisoning outside these limits may result in aircraft-to-tank collision.

The pilot must also attend to the status of all the installed missiles and insure that all appropriate switchology is correct. If the gunsight was set for bombing, it must be reset to 35 mils for firing missiles. The Sparrows should have been tuned and checked immediately after launch. The pilot should have selected an operating station following initial airborne checks. If not, he must now recall and select an operating station if the Sparrow is to be used. The coolant for the Sidewinders should have been turned on and the tone adjusted long before entering a hostile environment. Seeker head calibrations made earlier in the flight must now be recalled.

With the knowledge that all switches are properly positioned, the pilot should anticipate which weapon he will probably use first. In making this decision, he should consider what the relative position of the enemy will be when the missile is launched, if the aircraft radar is working, what the missile will be looking at in the background and in which missile the pilot has the most confidence. Once deciding, he will select either radar or heat along with missile arm. Failure to execute any of these preparations properly would probably result in the loss of a kill should the opportunity present itself.

Continuing the engagement, the pilot must make a positive determination of whether he is pursuing an enemy aircraft or not (Fig. 2, block E). He may have several inputs to aid in making this decision. The most important input, by far, is his visual contact with the suspect aircraft. The controlling agency may advise that enemy aircraft are known to be in the area. In making this

decision, the pilot must temper his aggressiveness and desire to 'kill a MIG' with sound judgement and patience. An incorrect snap decision in this situation could result in killing a friend or making him a prisoner of war.

Once determining that the suspect aircraft is an enemy aircraft, the pilot will continue to maneuver to a position from which he can deploy his weapons (Fig. 3, block F). At this point, the pilot should have the knowledge and confidence that all switches are set properly. The uncertainty that there is something not in its proper position would detract from the concentration necessary for the engagement. Switching from radar to heat or heat to radar, requires only one switch and should be accomplished with a minimum of distraction.

As the enemy aircraft is approached, the pilot should realize that he is flying a rather predictable flight path which could easily be taken advantage of by another enemy aircraft. He must keep a vigil for these other, as of yet unseen, enemy aircraft.

The opposing pilot has probably been notified that he is in danger by his GCI or perhaps another enemy aircraft (Fig. 3, block G). He will begin to maneuver his aircraft. The lead F-4 pilot must now counter the enemy maneuver and attempt to coordinate with his wingman. To do this effectively will require a great deal of knowledge of the pilot as well as a very high level of air combat maneuvering (ACM) ability. He should know the enemy's aircraft nearly as well as his own. (Where are his blind spots? How fast can he go? How well will his aircraft roll at high airspeeds? What is his turning capability? How long can he fight with the fuel he has available?) The F-4 pilot should know the enemy weapons capabilities thoroughly. He should assess the ability of his adversary. The enemy aircraft may

have some advantages but, if the enemy pilot is inferior, the combination is probably not potent. Any perceived or known weaknesses in the enemy should be exploited.

In performing these tasks, both mental and physical, the pilot is subjected to several interfering effects. Reacting to the maneuvers of the enemy requires nearly all of the pilot's visual and mental ability. However, the possibility of the presence of other enemy aircraft can't be forgotten or ignored. The pilot is certainly in a rather high pressure situation. If he loses, there is a chance that he might be killed or become a prisoner of war. This type of pressure certainly will degrade the pilot's memory and decision making capabilities to some degree. The ability to think clearly and process as many of the inputs as possible is mandatory for survival.

Physically, the pilot is also under a great deal of stress. For a majority of the engagement he will be under a greater than normal acceleration. This increased acceleration causes perspiration, decreased visual capabilities and may cause a high rate of fatigue. If the pilot's oxygen mask is slightly loose, it may droop making it very difficult to talk.

There is a very high probability that the engagement will take place at a very low altitude, a regime in which the pilot has very little ACM training. There are some maneuvers that the pilot will not be able to execute due to the proximity to the ground. Additionally, there is very little room to recover from an error such as a departure or stall.

Throughout the engagement, the pilot must monitor his fuel status, his position with respect to the carrier or a tanker and whether he is winning or losing the fight (Fig.

3, block H). If he has encountered a numerically superior enemy and maneuvered against some or one of them for any length of time, there is a possibility that one of the enemy pilot's will soon become a serious threat. If this occurs, rather than pressing recklessly for a shot, it would be prudent to maneuver in such a manner as not to be shot.

Once arriving in a missile envelope, the pilot must align the target properly and pull the trigger (Fig. 4, blocks I and J). After the missile separates from the aircraft, the pilot should determine if it is guiding or not. If it is not, he should fire another. If the trigger was pulled and no missile launched at all, that missile should be jettisoned unless the pilot is sure that the reason it did not leave was improper switchology.

More time was probably spent tracking the enemy aircraft just prior to a successful shot than the pilot realizes. He was quite vulnerable during this period of time. Therefore, immediately after the successful shot, he should check his rear hemisphere and locate his wingman (Fig. 4, block K).

C. IMPLICATIONS OF THE SKILL AND TASK ANALYSIS

The skill and task analysis demonstrates that during an ACM engagement the pilot's visual and auditory sensors as well as his mental and physical abilities are tasked very nearly to their capacity. These facts have three very important implications when considering the design of an energy management display. The first is that the display must be designed so that the pilot does not have to look away from the opposing aircraft for even a moment in order to see the display. The second is that whatever the display format is, it must be easily interpreted by the pilot. The

third implication is dichotomous. In order to be successful in ACM, it is incumbent upon the pilot to maneuver his aircraft as nearly as he possibly can to its optimum. It is also a fact that during an ACM engagement the pilot is placed in a very taxing situation both mentally and physically. The desirability of a device which would aid the pilot to maneuver the aircraft at its optimum during this complex tasking situation is clearly seen. However, it must be acknowledged that, also due to this complex tasking, even a well presented and easily understood display may be more than the pilot is able to correlate.

FLOW CHART OF SKILL AND TASK ANALYSIS

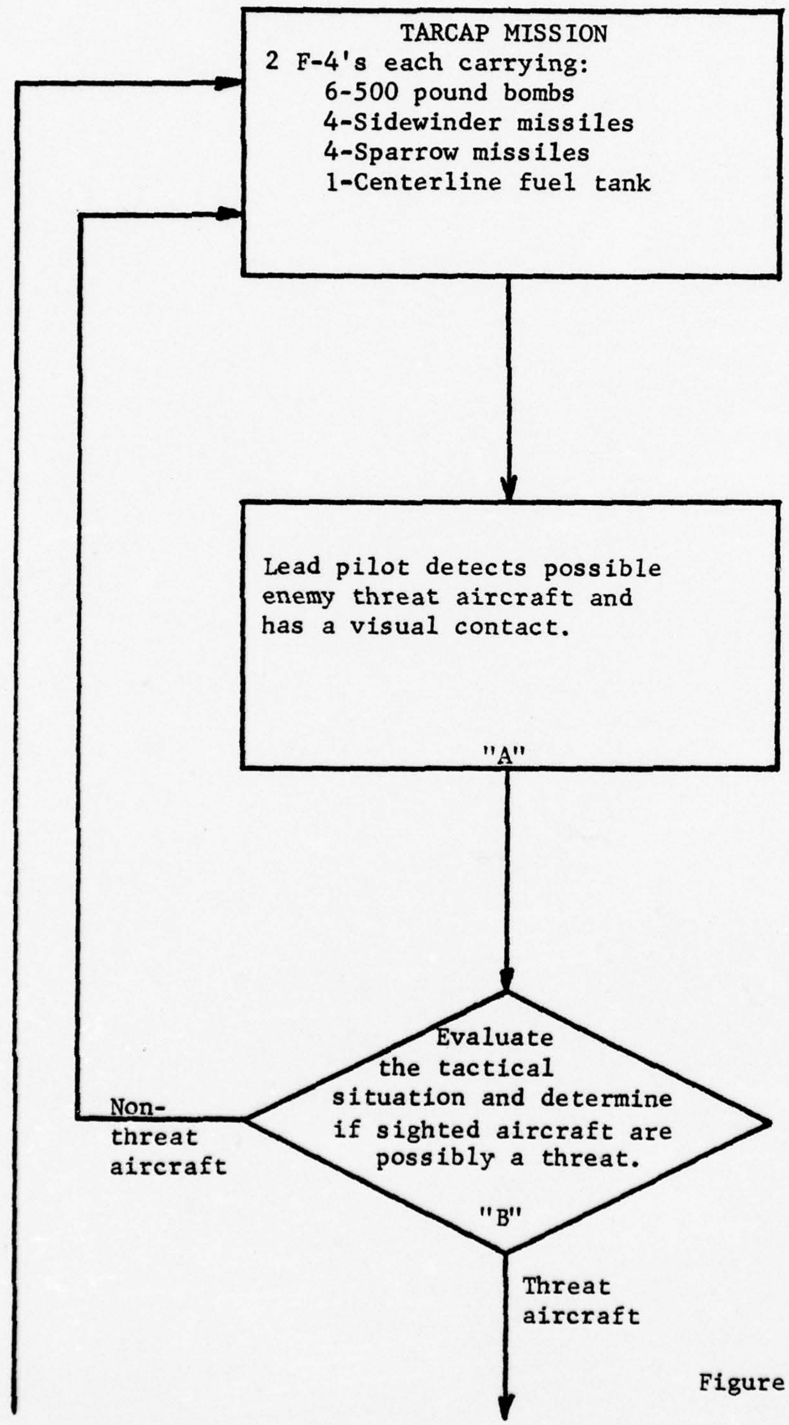


Figure 1

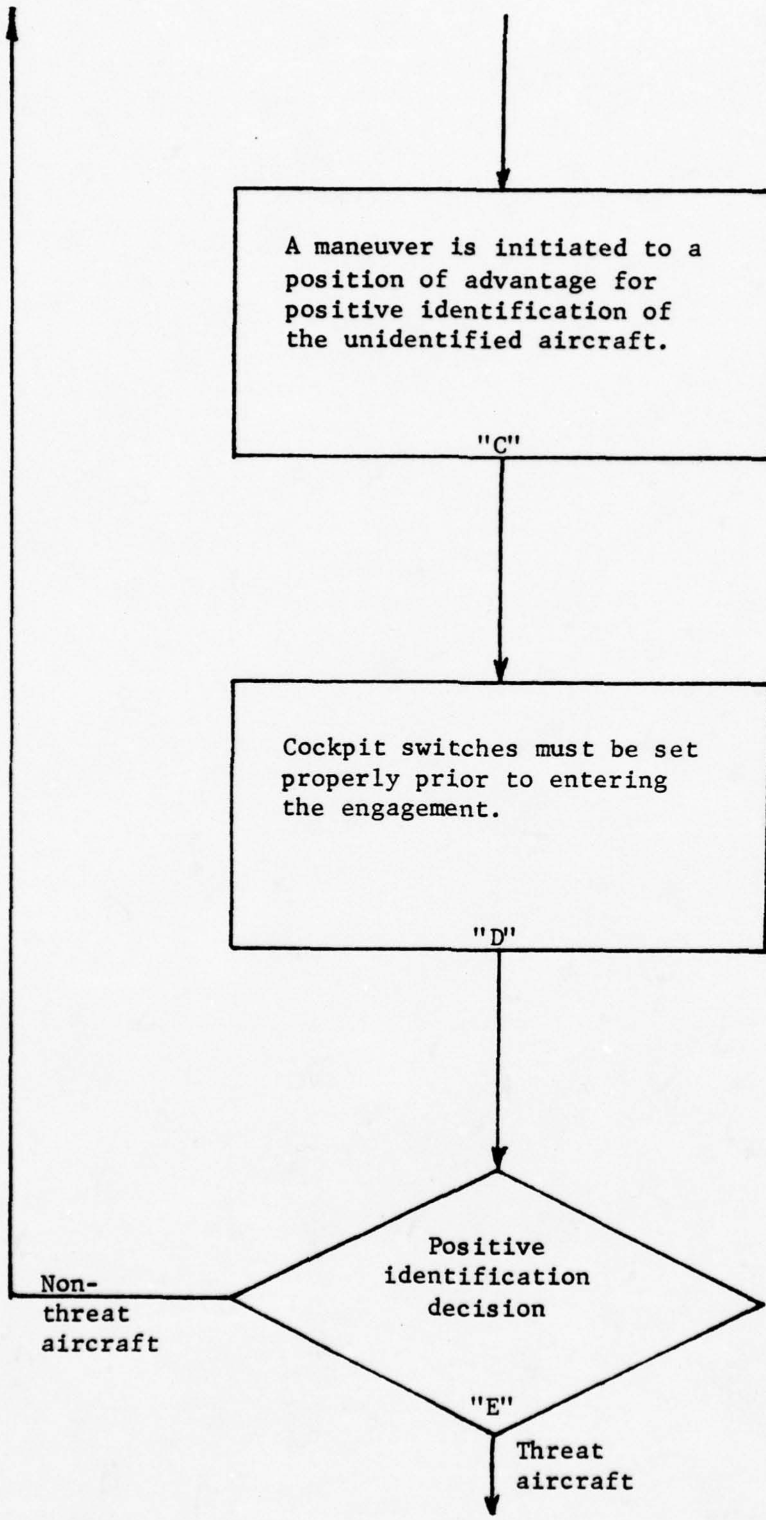

A maneuver is initiated to a position of advantage for positive identification of the unidentified aircraft.
"C"
Cockpit switches must be set properly prior to entering the engagement.
"D"
Positive identification decision
Non-threat aircraft
"E"
Threat aircraft

Figure 2

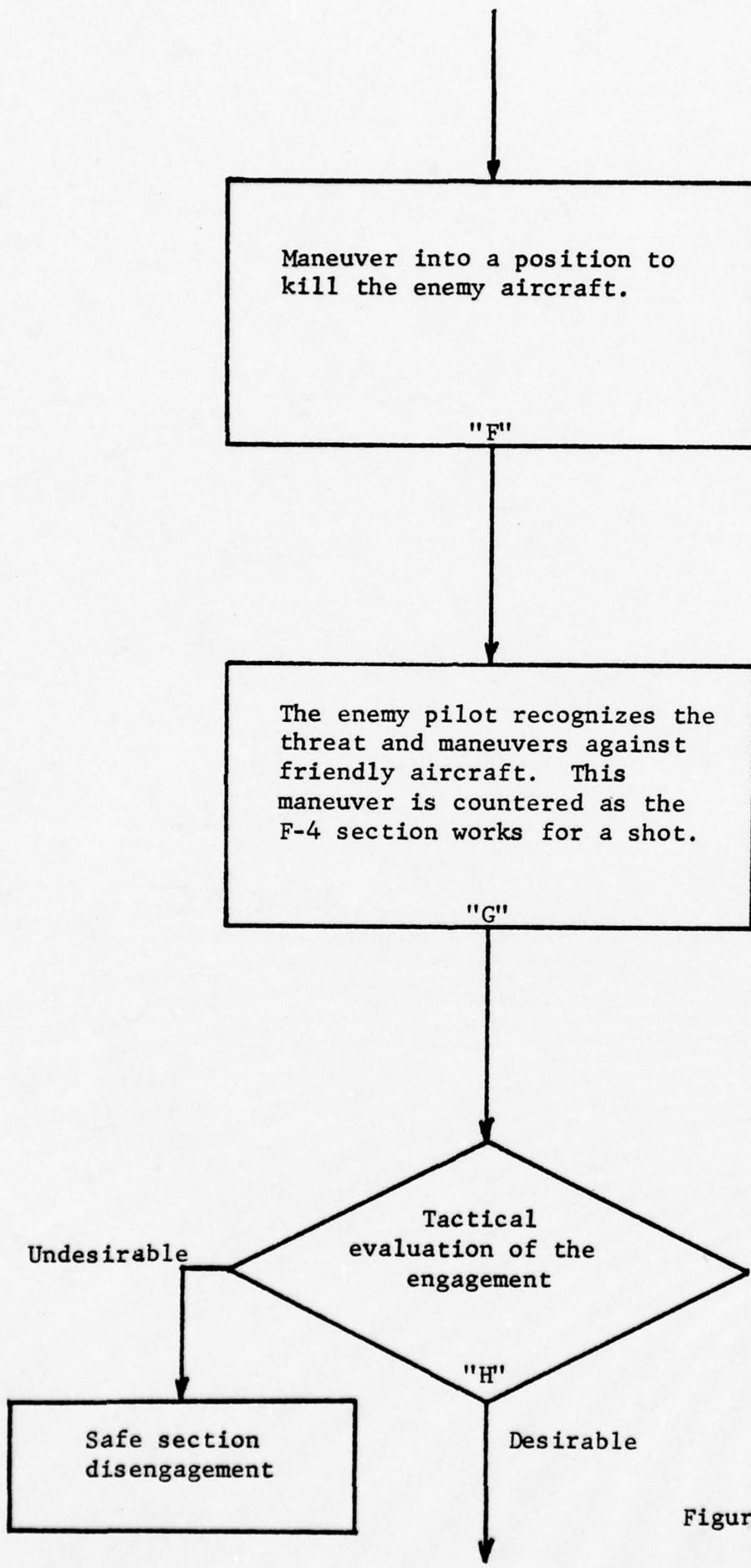

Maneuver into a position to kill the enemy aircraft.
"F"
The enemy pilot recognizes the threat and maneuvers against friendly aircraft. This maneuver is countered as the F-4 section works for a shot.
"G"
Tactical evaluation of the engagement
"H"
Undesirable
Safe section disengagement
Desirable

Figure 3

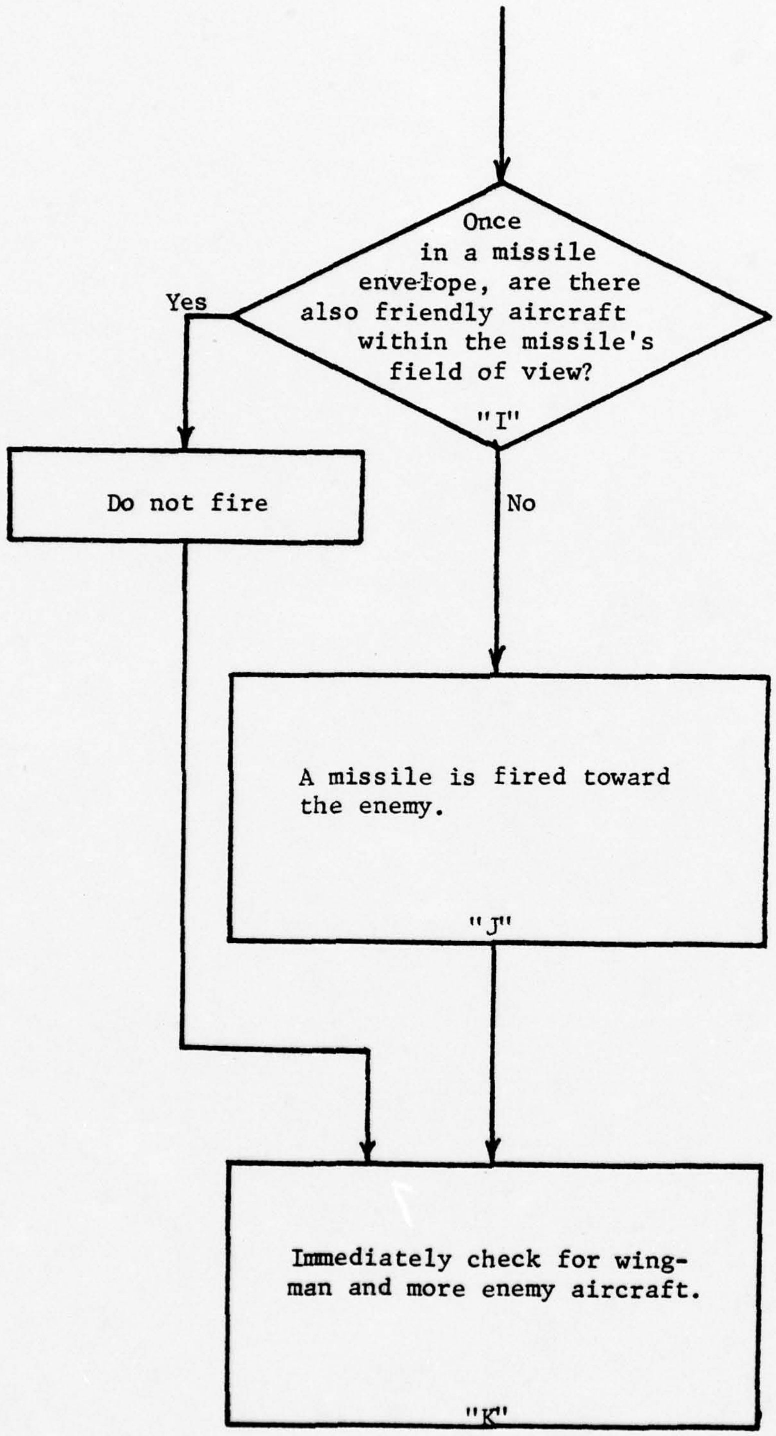

Once in a missile envelope, are there also friendly aircraft within the missile's field of view?
"I"
Yes
No
Do not fire
A missile is fired toward the enemy.
"J"
Immediately check for wingman and more enemy aircraft.
"K"

Figure 4

III. DESIGN OF AN ENERGY MANAGEMENT DISPLAY

A. JUSTIFICATION FOR DESIGN OF AN ENERGY MANAGEMENT DISPLAY

Although the skill and task analysis indicated the possibility that an energy management display (EMD) might not be viable in actual ACM, the presence of other factors in addition to the demonstrated desirability of such a device encouraged its design and construction. One of the key factors that encouraged such a display was consideration of the flight characteristics of future generation fighters. These aircraft will not have the flight buffet regions that have provided fighter pilots with 'seat of the pants' energy management in the past. Considering the proposed thrust-to-weight ratios of the next generation of fighters, it is conceivable that during ACM high enough levels of specific excess power would routinely exist which could result in airspeeds much higher than those for optimum turning performance. Having the capability to achieve and maintain too much airspeed while in ACM is exactly the opposite problem that fighter pilots have known in the past. Thus, the utility of an EMD in the next generation of fighters as well as those currently in use was considered favorable.

Applications of an EMD in a training environment were also considered positive. Rather than teaching a pilot optimum maneuvering techniques and energy management solely through a long series of trial-and-error experiences, using an EMD during training flights, the new ACM pilot would have

a continuous reference to the textbook version of energy management. It was felt that this would increase the instruction received from each training flight.

A further derivative benefit of an EMD was seen to exist in the field of aviation safety. The Naval Safety Center conducted a review of all aircraft accidents that occurred from July 1969 through April 1974 in preparation for a safety symposium. These records were examined by experienced safety center analysts to determine which of the contributing cause factors could have been avoided with the employment of some type of cockpit display. Attributed to the lack of V-N envelope information to the pilot, which an EMD would provide, were 42 aircraft destroyed, 8 aircraft damaged and 27 fatalities. The Commanding Officer of the Naval Safety Center endorsed the development of cockpit displays saying, "As a participant in the symposium described in ref. A, COMNAVSAFCEN strongly supports the urgent requirement for development and application of advanced technology in the area of cockpit displays" (COMNAVSAFCEN, Norfolk, Va., PR 250731Z Apr 74).

B. BASIC EMD DESIGN CONCEPTS

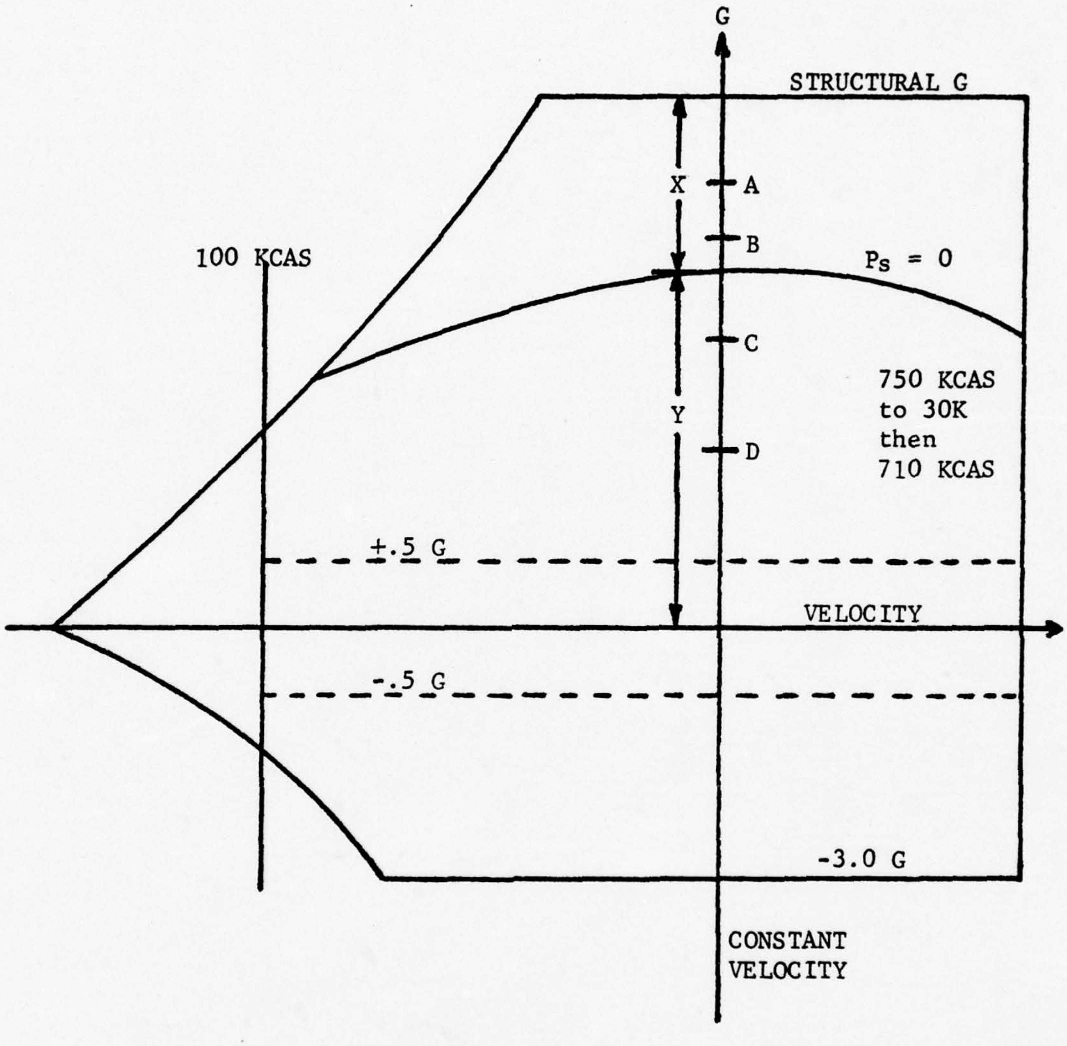
The basic design precept of this project was to provide the pilot with an additional sensory input to aid him in optimizing aircraft maneuvers during an ACM engagement. It was acknowledged that in an ACM engagement, the pilot maneuvers his aircraft in a manner to counter and exploit the tactics of his advisary. Therefore, no effort was made to tell the pilot where on the V-N diagram he should fly. The display was designed to aid the pilot in optimizing the maneuver he selects from the energy state that he initiates it.

Specific design concepts adopted were those directly implicated by the skill and task analysis of ACM. A primary concept to which the design was committed was that the pilot not be required to move his eyes off of the enemy aircraft in order to utilize the EMD. Directly associated with this concept was the requirement that the display be easily interpreted. A constraint placed upon these two specific design concepts was that the display effectively portray the maneuverability diagram, especially the maneuvering limits and regions of optimum performance.

C. IMPLEMENTATION OF DESIGN CONCEPTS

In order to provide the pilot with a display that would cause a minimum of visual distraction and interference, it was decided that the display be placed in the pilot's peripheral vision region. Using this region of vision and requiring that the pilot not look away from his target implied that the display format be extremely simple and intuitive. To satisfy these requirements, colors were employed in a manner similar to a standard traffic light. As envisioned, the display would consist of 4 colored bands mounted on the inside of the pilot's helmet visor above his eyes, but within his peripheral vision region. It was felt that the employment of colors would provide a great deal of positive transfer and thus avoid the necessity of learning sight pictures.

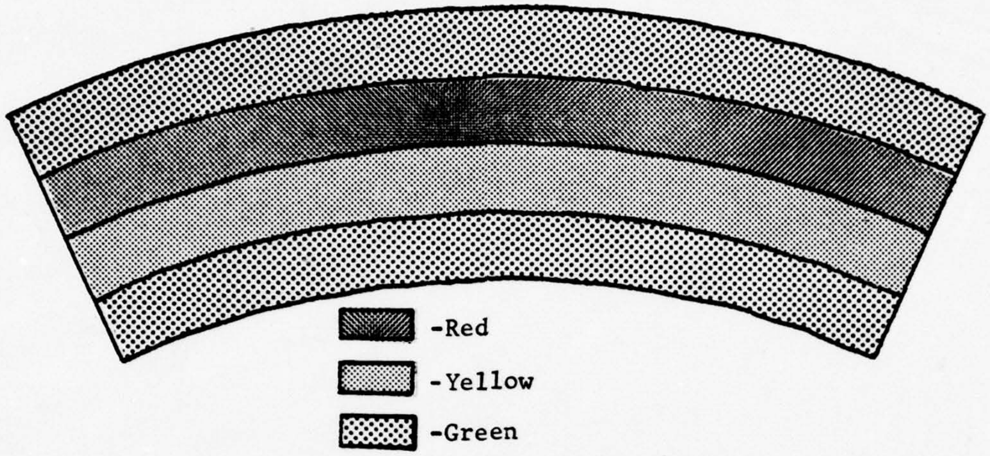
An F-4J was used as a model for this project. The maneuverability diagram was partitioned as shown in Fig. 5. It was color coded into seven basic regions based on their relative position to the zero specific power curve (Fig. 6). These regions are displayed using four rows of colored lights (Fig. 6). The lower row of green lights is used to



A = NEUTRAL G + 1/2 X
B = NEUTRAL G + 1/8 X
C = NEUTRAL G - 1/8 Y
D = NEUTRAL G - 1/2 Y
NEUTRAL G = THE G AT WHICH $P_s = 0$

Figure 5 - PARTITIONING OF MANEUVERABILITY DIAGRAM

Figure 6 - COLOR CODING OF EMD



	Upper green	Blink red	Stdy. red	Yellow	Stdy. lwr. green	Blink lwr. green
Airspeed > corner velocity	X					
Airspeed < 100 KCAS		X				
Airspeed > 750 KCAS below 30K		X				
Airspeed > 710 KCAS at/above 30K		X				
G ≤ -3 G		X				
G ≥ positive structural G		X				
A ≤ G < structural G			X			
B ≤ G < A			X	X		
C < G < B				X		
D < G ≤ C				X	X	
+.5 < G ≤ D					X	
-.5 ≤ G ≤ +.5						X
-3 < G < -.5					X	

represent positive specific power. This row is blinked to distinguish the region of optimum energy addition (very high excess specific power) that exists between +.5G and -.5G. A solid lower green row represents a high level of excess specific power while the solid lower green and yellow rows together represent a lesser level of excess specific power. The yellow row alone represents the region immediately surrounding the zero specific power curve. The yellow and red rows indicate a low level of negative specific power while the red row alone indicates a high level of negative specific power. A blinking red row alone is used to indicate to the pilot that a basic VN diagram limit has been exceeded. The upper green row is illuminated when corner velocity has been attained and is out if not. An example of an F-4J maneuverability diagram (Fig. 7) as color coded by this scheme is shown in Fig. 8.

D. TECHNICAL REALIZATION OF THE DESIGN

A 8008 microprocessor was used for dedicated control of the EMD. A microprocessor was selected to control the display for three reasons. The first was that the speed of a microprocessor allows the desired information to be presented with essentially no processing delay in a real-time mode. The second was that the size, weight and durability cf a microprocessor make it easily adaptable to carrier based fighter and attack aircraft. The third was that the microprecessor when compared with alternative methods is relatively inexpensive and simple.

The three pieces of information needed to determine uniquely the specific power of an aircraft at any given instant are airspeed (in knots calibrated airspeed), altitude (in feet above mean sea level) and aircraft

F-4J MANEUVERABILITY DIAGRAM

MAXIMUM POWER
20,000 FEET
GROSS WEIGHT - 37,500 POUNDS

REMARKS

(2) J79-GE-10 ENGINES

PLANE CONFIGURATION
[illegible] AIM-7E AND (4) AIM-9D

NOTE

ACCELERATION PLACARD WITH AIM-[illegible] MISSILES AT STATION [illegible] AND [illegible] IS [illegible] G FOR GROSS WEIGHT DEPICTED. FOR COMPLETE AIM-[illegible] ACCELERATION LIMITATIONS REFER TO APPENDIX [illegible]

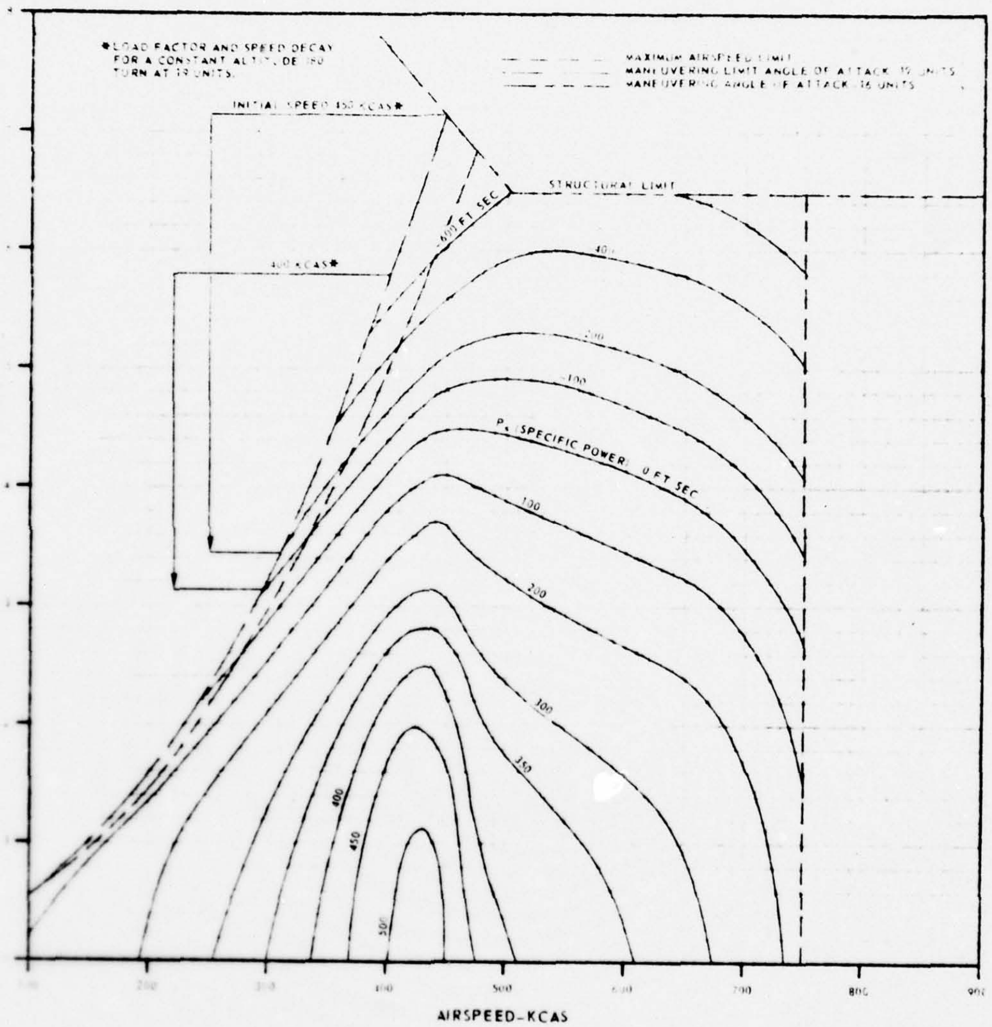


Figure 7 - F-4J MANEUVERABILITY DIAGRAM

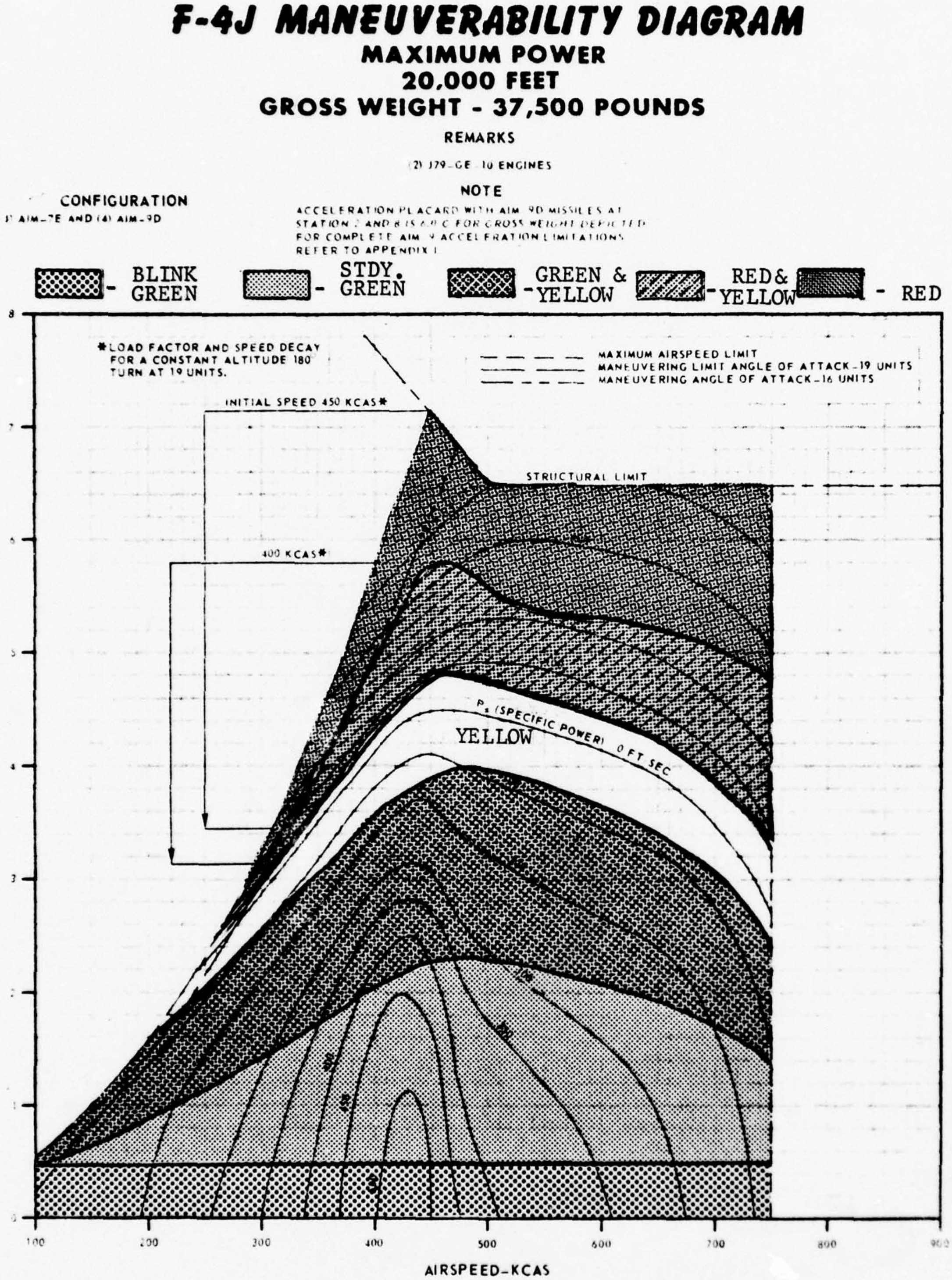


Figure 8 - COLOR CODED F-4J MANEUVERABILITY DIAGRAM

acceleration (in G's). This information was input to the microprocessor in an 8-bit format (one byte). The airspeed was scaled from 0 to 2550 KCAS in 10 KCAS increments, the altitude from 0 to 51000 feet MSL in increments of 200 feet and the G from -3.75 to +9.00 G's in .05 G increments (Fig. 9).

The airspeed was scaled much higher than it actually needed to be. Only 7 bits of airspeed would provide a range of 0 to 1270 KCAS which is completely satisfactory. The most significant bit of airspeed could easily be used to input whether or not the throttles were in afterburner or not. Doing this would expand the scope of the EMD to include both the military and maximum power maneuverability regimes. Although not accomplished in this project, if this EMD design were actually employed in operational aircraft, this expansion would greatly contribute to the accuracy and credibility of the display.

A single routine was designed to satisfy the criteria of the proposed output display (Figs. 5 and 6). A single routine was constructed rather than a program which calls several subroutines because using subroutines would not result in a savings of memory space. A single routine program was written in essentially three blocks using the high level programming language PL/M (Appendix B). In conjunction with this program, a look-up table was established containing scaled values of structural G or 20 units angle of attack and the G for specific excess power equal to zero for a given airspeed. For this project, the look-up table was constructed with data for the F-4J at maximum power from sea level to 30000 feet using unamended maneuverability diagrams. It is structured as shown in Fig. 9.

It was decided that only one input port (8 bits) and one

INPUT SCALING

AIRSPEED	ALTITUDE	G
0-2550 KCAS IN 10 KCAS INTERVALS	0-51000 FEET MSL IN INTERVALS OF 200 FEET	-3.75 TO +9.00 G's IN .05 G INTERVALS

MEMORY ADDRESSING

STRUCTURAL G AND NEUTRAL G (P_S=0) FOR FOUR ALTITUDE BLOCKS ARE PLACED IN THE LOOK-UP TABLE G$STO IN 10 KCAS INCREMENTS FROM 100 TO 750 KCAS.

ALTITUDE BLOCK	(MEMORY$SELECT) SECTION OF G$STO
0-5000 FEET	0
5000-15000 FEET	1
15000-25000 FEET	2
25000-35000 FEET	3

USING SCALED AIRSPEED, THE LOCATION WITHIN EACH SECTION MAY BE DETERMINED.

I.E. FOR 20000 FEET AND 400 KCAS
MEMORY$SELECT = 2
LOCATION = (2 * 132) + 2 * (40 - 10) = 324
STRUCTURAL$G = G$STO (324)
NEUTRAL$G = G$STO (325)

Figure 9

output port (8 bits) be used in order to keep the input output hardware requirements of the microprocessor to a minimum. The first block of the program was devoted to controlling the multiplexers (Fig. 10) which enabled the use of only one input port vice three. Additionally, the first block was used to input the airspeed, altitude and G, to check the airspeed against structural limit airspeed, to determine in which section of the look up table the required data was located and to establish the corner velocity for the input altitude.

The second block of the program, called energy, was structured to locate the required data within the previously determined section of the look-up table and to check the input G against structural limit G or the 20 unit angle of attack G. It also partitions the maneuverability diagram with respect to the G for specific excess power equal to zero for the input airspeed (Fig. 5) while determining the appropriate display configuration based on Fig. 6.

The third block of the program, called display, was designed to determine the appropriate value for the single output port used, based upon the values of the variables light and key. The values of these byte variables were set in binary form throughout the program using the six least significant bits of each. In this manner, each bit of the sum of light and key, called lek, was able to have an independent function. The two most significant bits of the output port are used for control of the multiplexers. The entire software logic is depicted in flow chart format in Figs. 11, 12 and 13. The resulting employment of the microprocessor is shown in Fig. 14.

The single output port serves as a control for both the EMD and the multiplexers. The logic network used for the EMD and the significance of the eight bits of the output

MULTIPLEXING SCHEME

```
     MULTIPLEX = 01000000B;
     OUTPUT(1) = NOT(00000000B);
     LEK = 00000000B;
START:  KEY = 00000000B;
     LIGHT = 00000000B;
     ALTITUDE = INPUT(1);
     LEK = MULTIPLEX + LEK;
     OUTPUT(1) = NOT(LEK);
     AIRSPEED = INPUT(1);
     LEK = MULTIPLEX + LEK;
     OUTPUT(1) = NOT(LEK);
     G = INPUT(1);
          .
          .
          .
          .
DISPLAY:  IF LIGHT = 00000001B THEN LEK = 00000001B;
          ELSE LEK = LIGHT + KEY;
     OUTPUT(1) = NOT(LEK);
     GO TO START;
```

```
MULTIPLEX SELECT CODE
    ALTITUDE = 00
    AIRSPEED = 01
           G = 10
```

THE TWO MOST SIGNIFICANT BITS OF OUTPUT(1), WHICH CONTROL THE MULTIPLEXERS, ARE ZERO EACH TIME PROGRAM EXECUTION RETURNS TO "START." "MULTIPLEX" IS ADDED TO "LEK" TWICE. ALTITUDE IS INPUT BEFORE THE FIRST ADDITION, AIRSPEED BEFORE THE SECOND ADDITION AND G AFTER THE SECOND ADDITION. IN THIS MANNER THE MULTIPLEXERS ARE CONTROLLED WITHOUT AFFECTING THE LIGHT CONTROL.

Figure 10

SOFTWARE LOGIC

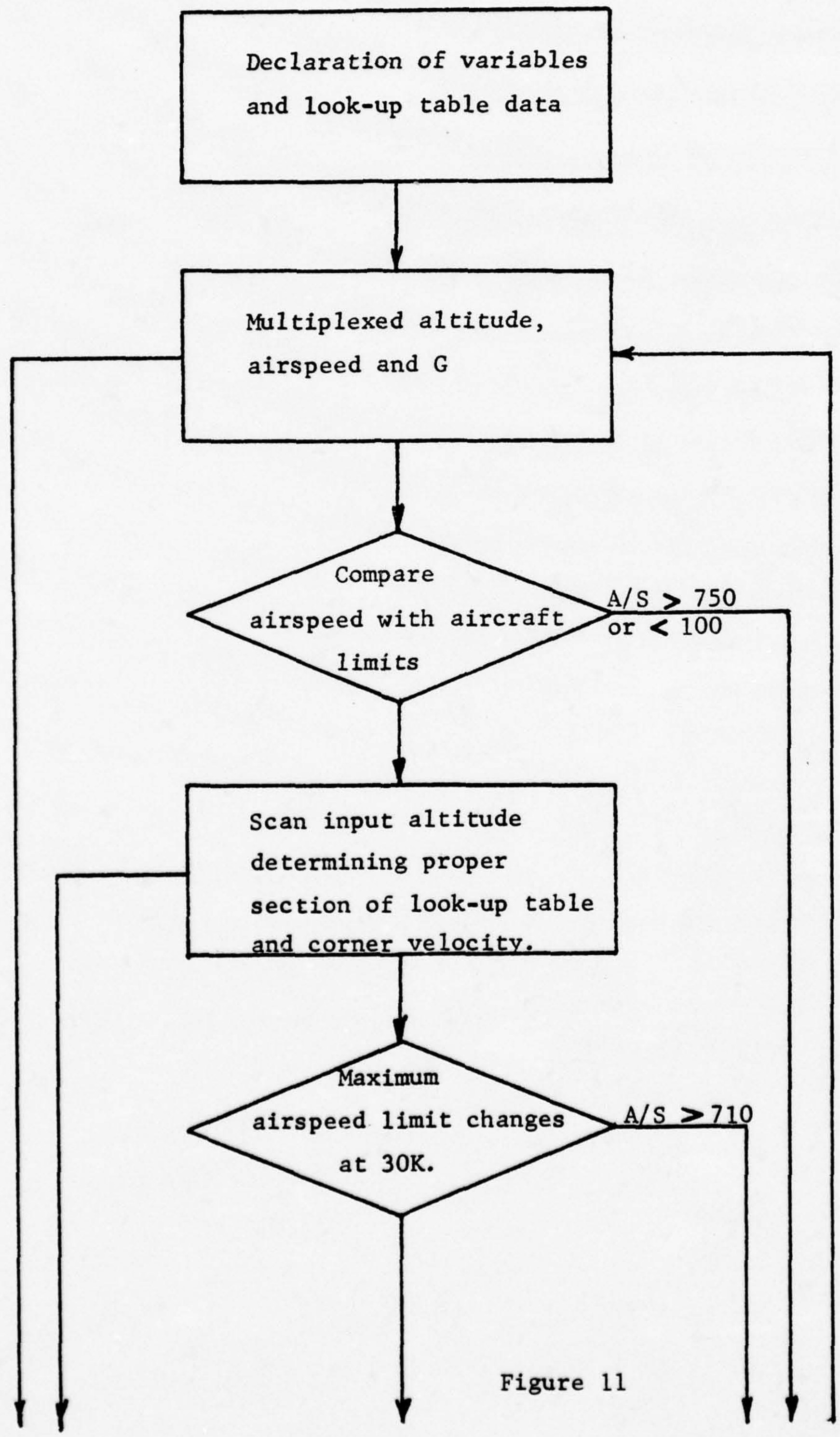


Figure 11

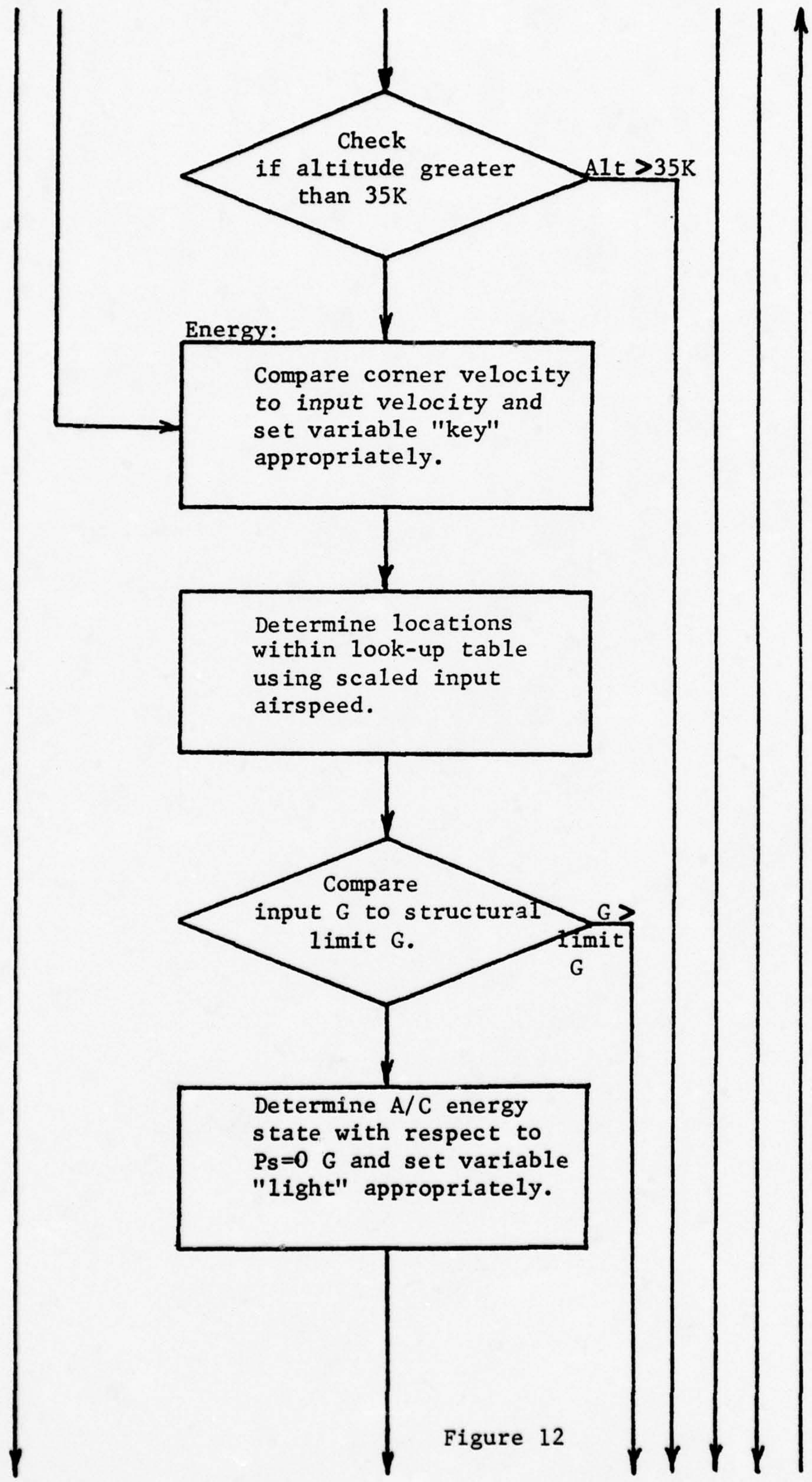

Check if altitude greater than 35K
Alt >35K
Energy:
Compare corner velocity to input velocity and set variable "key" appropriately.
Determine locations within look-up table using scaled input airspeed.
Compare input G to structural limit G.
G > limit G
Determine A/C energy state with respect to Ps=0 G and set variable "light" appropriately.

Figure 12

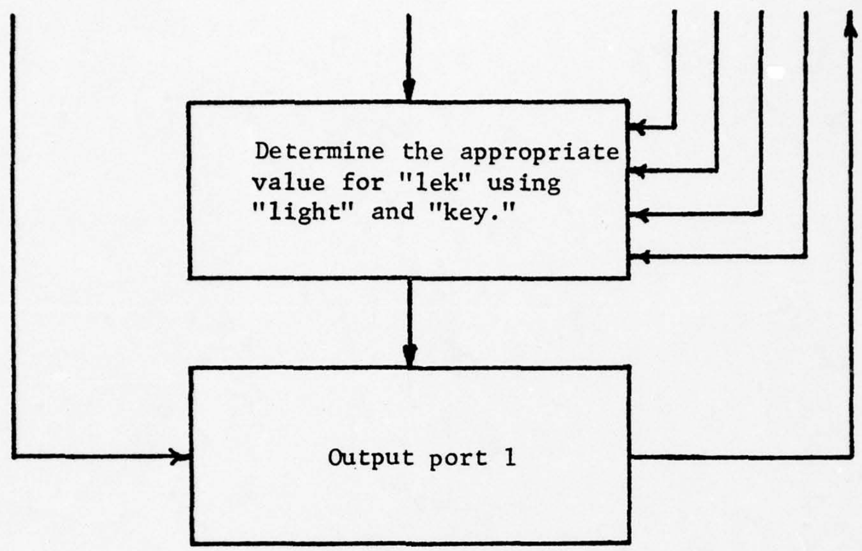

Determine the appropriate value for "lek" using "light" and "key."
Output port 1

Figure 13

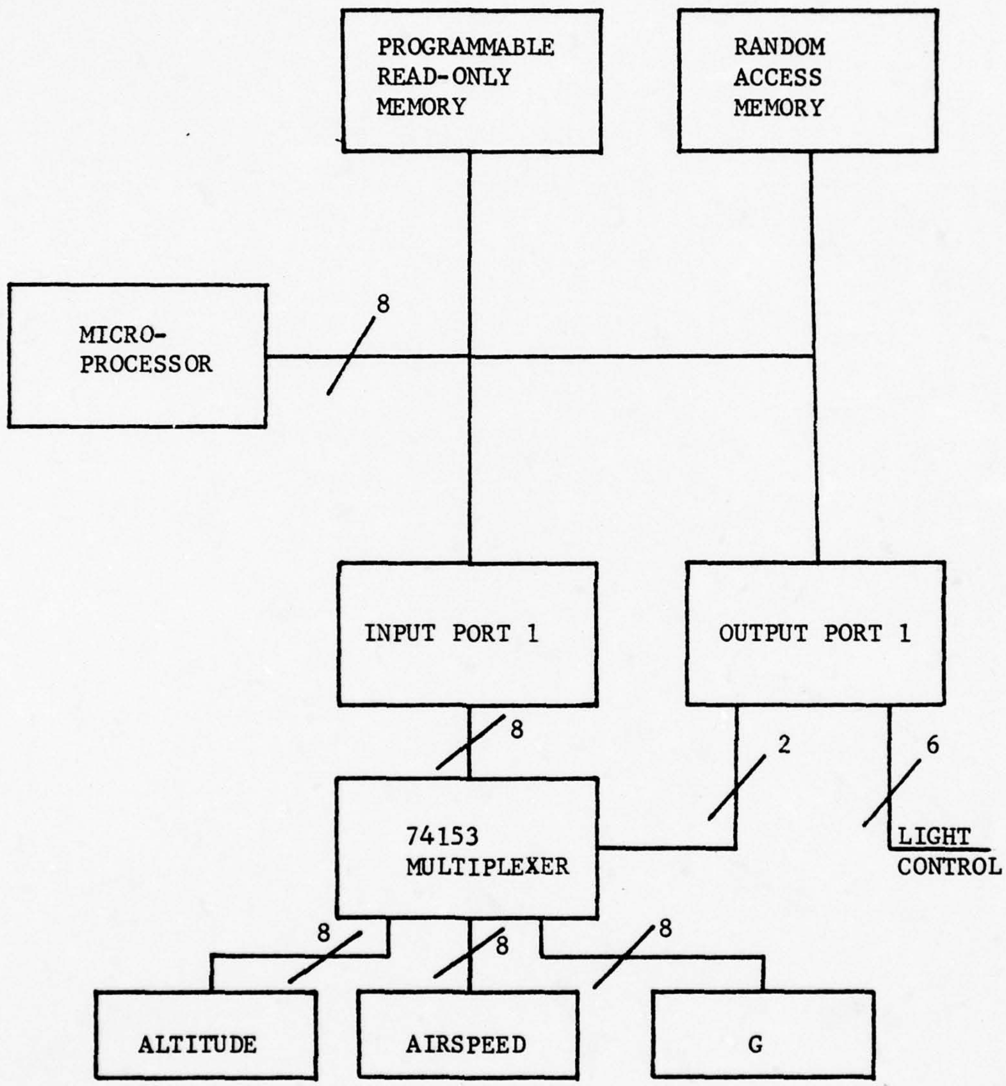


Figure 14 - EMPLOYMENT OF THE MICROPROCESSOR

port are shown in Fig. 15. The two bits used for multiplexer control required no logic processing and were routed directly to the multiplexer chips.

Three sets of clock counter circuits (Fig. 16) were designed to simulate airspeed, altitude and G for purposes of conceptual demonstration. All three circuits were exactly the same and produced the required data in an 8-bit format. Each circuit was controlled by a 3-position switch which caused the counters to count up or down or hold their present state.

Rather than using a conventional clock to drive the counters, a 555 chip was used in an astable mode (Appendix C). This was done so that each counter could have its own oscillator which was easily adjustable by changing the circuit resistance. The counters consisted of two synchronous 4-bit binary up/down counters cascaded to provide a single 8-bit up/down counter. The value of each counter was monitored by a set of labeled red LED's (light emitting diodes). Four 4-line to 1-line data multiplexers, controlled by program logic, were used to enable the use of a single input port (Fig. 16). Four rows of colored LED's were constructed as shown in Fig. 15 to demonstrate the effectiveness of the display design.

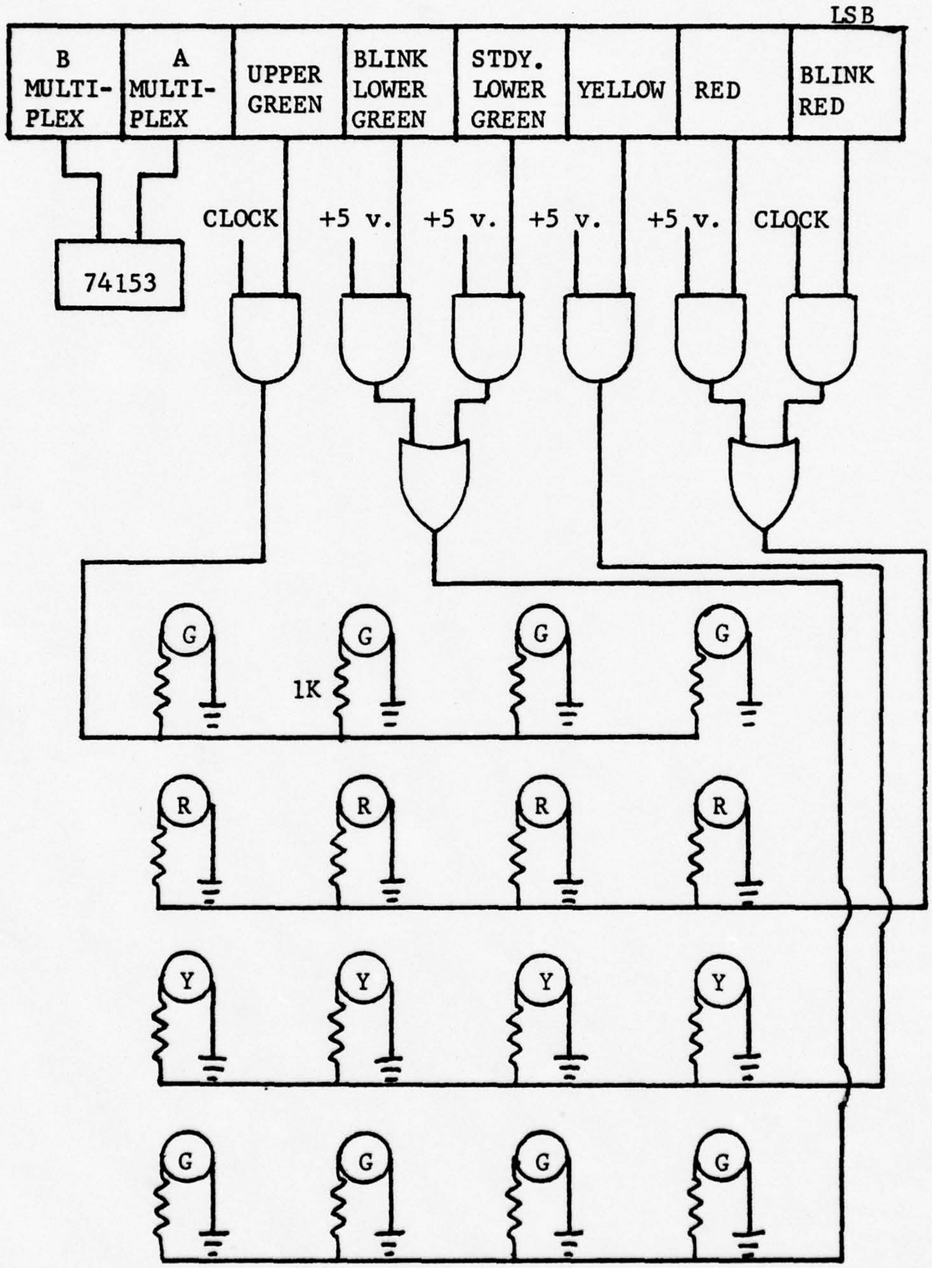


Figure 15 - OUTPUT HARDWARE

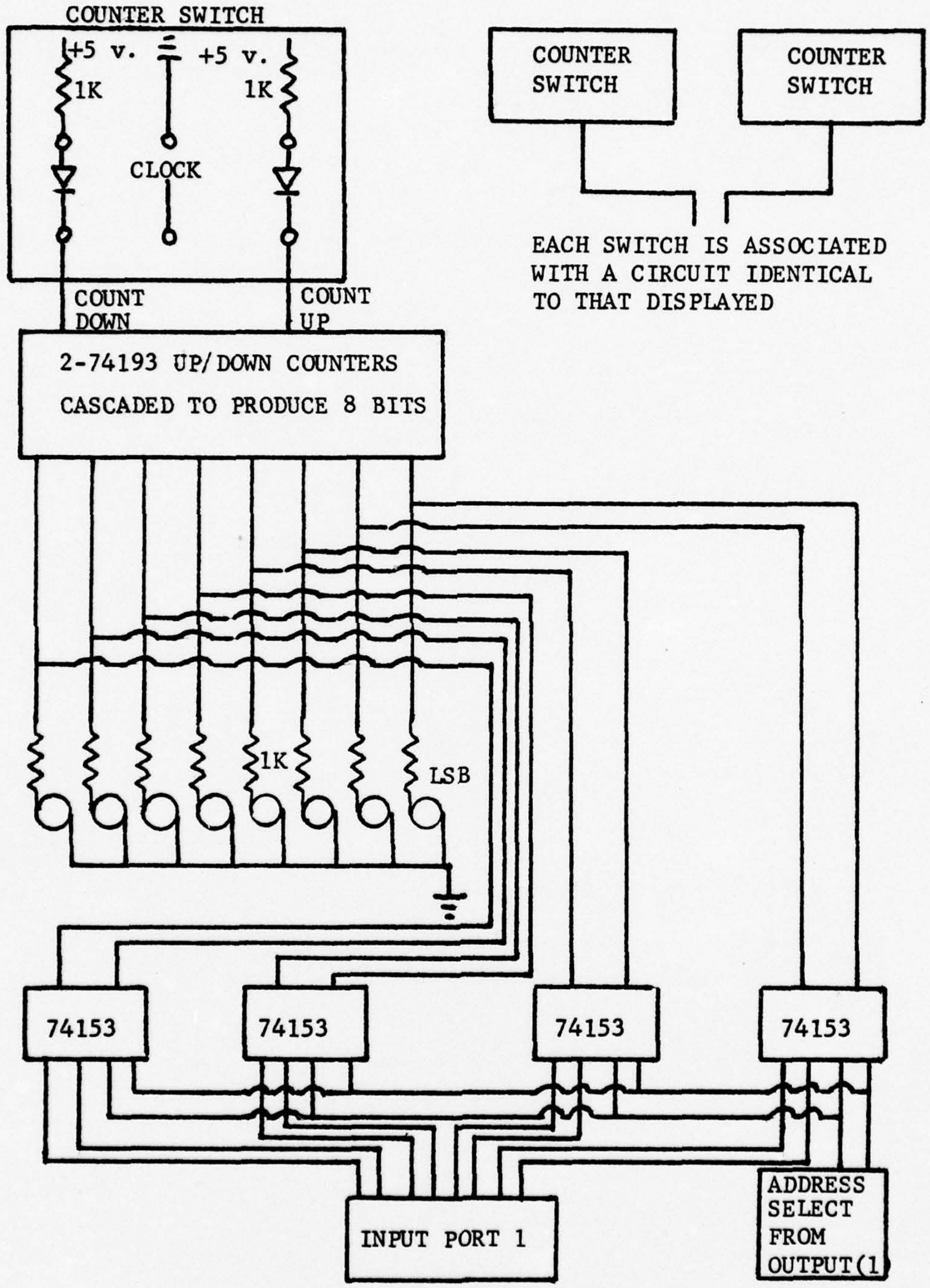


Figure 16 - INPUT HARDWARE

IV. EXPERIMENTAL DESIGN AND TESTING TO DETERMINE EMD/HUMAN OPERATOR COMPATIBILITY

A. PURPOSE AND SCOPE OF EXPERIMENTAL DESIGN

The utility and desirability of an EMD for ACM was demonstrated in the skill and task analysis of ACM. Also recognized in this analysis was the possibility that the pilot's visual and auditory sensors were tasked very nearly to the saturation level. Due to this saturation, it was acknowledged that a significant degradation of critical visual responsibilities might occur as a result of the addition of an EMD to the visual scan. An experiment was designed to determine the level of the resulting degradation, if any at all resulted.

As indicated in the skill and task analysis, the most important visual responsibility of a pilot involved in ACM is to gain and maintain sight of the enemy aircraft. If the interpretation and utilization of a device, such as the proposed EMD, resulted in a decreased ability of the pilot to maintain visual contact with the enemy, this device should be considered ineffectual in ACM. The experiment was therefore structured with a primary task representing the concentration and visual attention required to maintain sight of the opposing aircraft during ACM and a secondary task which required interpretation and response to the EMD. Using attack and fighter pilots as subjects, a data base was established for only the primary task. Once establishing a level of performance for each pilot for only the primary

task, the secondary task was introduced and its effect on the primary task determined.

B. STATEMENT OF HYPOTHESIS

The scientific hypothesis adopted was that the introduction of the proposed EMD to the pilot's visual scan would not alter his ability to perform critical visual functions. The more specific and easily testable statistical hypothesis adopted was that the established levels of performance of a primary tracking task performed by attack and fighter pilots would not be degraded by the introduction of a secondary task requiring interpretation and response to the proposed EMD.

The statistical hypothesis was tested in this experiment. A significance level of .05 (less than a .95 probability that there is a significant difference) was established for acceptance of the statistical hypothesis.

C. EXPERIMENTAL METHODS

1. Structure of Hypothesis Test

All subjects listened to the same set of taped instructions (Appendix A) prior to the first primary task learning session. Each of four primary task learning sessions consisted of performing five, 100-second tracking tasks. Each two-dimensional task consisted of maintaining a small dot of light within a one inch circle on the face of a cathode ray tube display. The dot was controlled by the

subject deflecting a standard aircraft stick. Scoring of the task consisted of a timer being actuated whenever the dot was within the one inch target circle.

The tracking task was used to simulate the mental and visual concentration necessary to maintain sight of an enemy aircraft during ACM. The five, 100 second tasks were recorded onto a tape in order to present identical tasks to each subject during every session. The tasks were designed so that an experienced subject could achieve a 50 to 70 percent time on target score for the primary task alone.

The four learning sessions were used to establish a learned tracking score (LTS) for each subject. It was assumed that a subject's tracking task score, the dependent variable of the experiment, would not improve significantly after the fourth learning session. An LTS was established for each of the five runs using the highest score achieved on the individual runs during the learning sessions. The object of establishing an LTS was to establish a benchmark for each subject which would be sensitive to the addition of a secondary task in a time sharing mode. Using the highest score on each run as the LTS biased the experimental results toward rejecting the hypothesis when it might be true. It was felt that using an average as the LTS might cause the hypothesis to be accepted when it was actually false.

Prior to the fifth session, each subject listened to a second set of taped intructions (Appendix A). This set of instructions described the format of the presentation of the dual tasking stimuli. Included in this instruction set was a review of the maneuverability diagram, a review of the meaning of specific power and an explanation of the color coding of the EMD. After listening to the taped instructions, each subject performed the first two tracking runs to assure that they were in the region of their

established LTS. The LTS's for the first two runs were then modified using the test run scored if they were higher than the previously established LTS for the corresponding run. The third tracking run was then given as a learning period for the secondary task, the independent variable of the experiment. During this unscored practice run, each subject was given the opportunity to perform both tasks in a time-sharing environment.

The secondary task consisted of interpreting and responding to the EMD. The subjects were challenged five times during each of the five, 100 second tracking runs. A subject was challenged by the activation of a tone in the cockpit. Simultaneous to the activation of this tone, a timer was started and one of fourteen possible display configurations was randomly selected and illuminated. The display was mounted over the cathode ray tube in the peripheral vision region of the subject. This configuration was used to simulate as nearly as possible the visual requirements that would be presented during ACM with a helmet mounted version of the proposed EMD. Associated with the challenge was a response box located on the left console where the throttles would normally be located. The possible display configurations were placed in five basic categories each of which had an associated button on the response box. If the subject responded correctly to the challenge, the tone would go off, the response timer would go off and the display would be extinguished. The display would remain on until the correct response was initiated by the subject. The number of incorrect responses, if any, were counted and displayed to the operator.

During the fifth session the response times, the number of incorrect responses and the tracking task scores were recorded. The tracking task time for each of the five runs was compared with the LTS for the corresponding run to

determine the effect, if any, that the addition of the secondary task had on the primary task.

2. Subjects

The subjects selected for this experiment were 9 attack pilots and 9 fighter pilots. It was felt that using subjects from only these two communities would provide a representative cross section of those pilots most likely to use an EMD in the future. It was also assumed that subjects with fighter and attack background would grasp the purpose and concepts related to an EMD more rapidly.

The subjects were students of the Naval Postgraduate School and the Aviation Safety School. All subjects were designated pilots. The average age of the subjects was 31 years ranging from 28 to 36 years old. Thirty nine percent of the subjects had Vietnam combat experience. All of the subjects had served at least one operational tour and had not flown operationally in 14 months. The subjects had an average of 1853 flight hours ranging from 880 to 3400 hours.

3. Mechanization of the Experiment

An obsolete F-105 cockpit was used for this experiment. The interior of the cockpit was completely stripped with the exception of the ejection seat and remodeled to avoid the introduction of nuisance variables. The cockpit was equipped with a standard aircraft center control stick. Stick feel and centering were provided mechanically with the use of springs. One-turn potentiometers were mounted and geared to both the longitudinal axis (fore/aft stick) and the directional axis (right/left stick) in order to provide an electrical monitor

of stick motion to the analog computer.

A 10 inch by 8 inch cathode ray tube was also mounted in the cockpit. This screen was mounted so that its center was directly in front of the subject's eyes at a distance of 24 inches. A display panel was installed that surrounded the screen and filled in the remainder of the cockpit front panel area above the subject's legs. Four rows of colored LED's in the configuration of Fig. 6 were mounted over the screen in the peripheral vision region of the subject (Fig. 17). This display arrangement was used to simulate the visual demands that a helmet mounted EMD would require. Target dot intensity and focus knobs were located below the screen. A red LED was placed at the right base of the scope screen and was illuminated when the target dot was within the one inch radius target circle surrounding the scope center. A green LED was placed at the left base of the scope screen to indicate to the subject that a scoring run was in progress.

A response box was mounted on the left console in the position of a throttle. This box had five push button switches representing the five basic categories into which the possible display configurations were grouped (Fig. 18). The output of each switch was grounded until depressed at which time it became five volts. Each switch was labeled with the category that it represented in order to aid the subject in learning the EMD/response button correlations.

The circuit of the TR-10 analog computer, shown in Fig. 19, was used to provide the subject with a target dot that had longitudinal/directional response dynamics that were similar to those of a stable aircraft. The inputs for these circuits came directly from the potientiometers mounted on the axes of the stick.

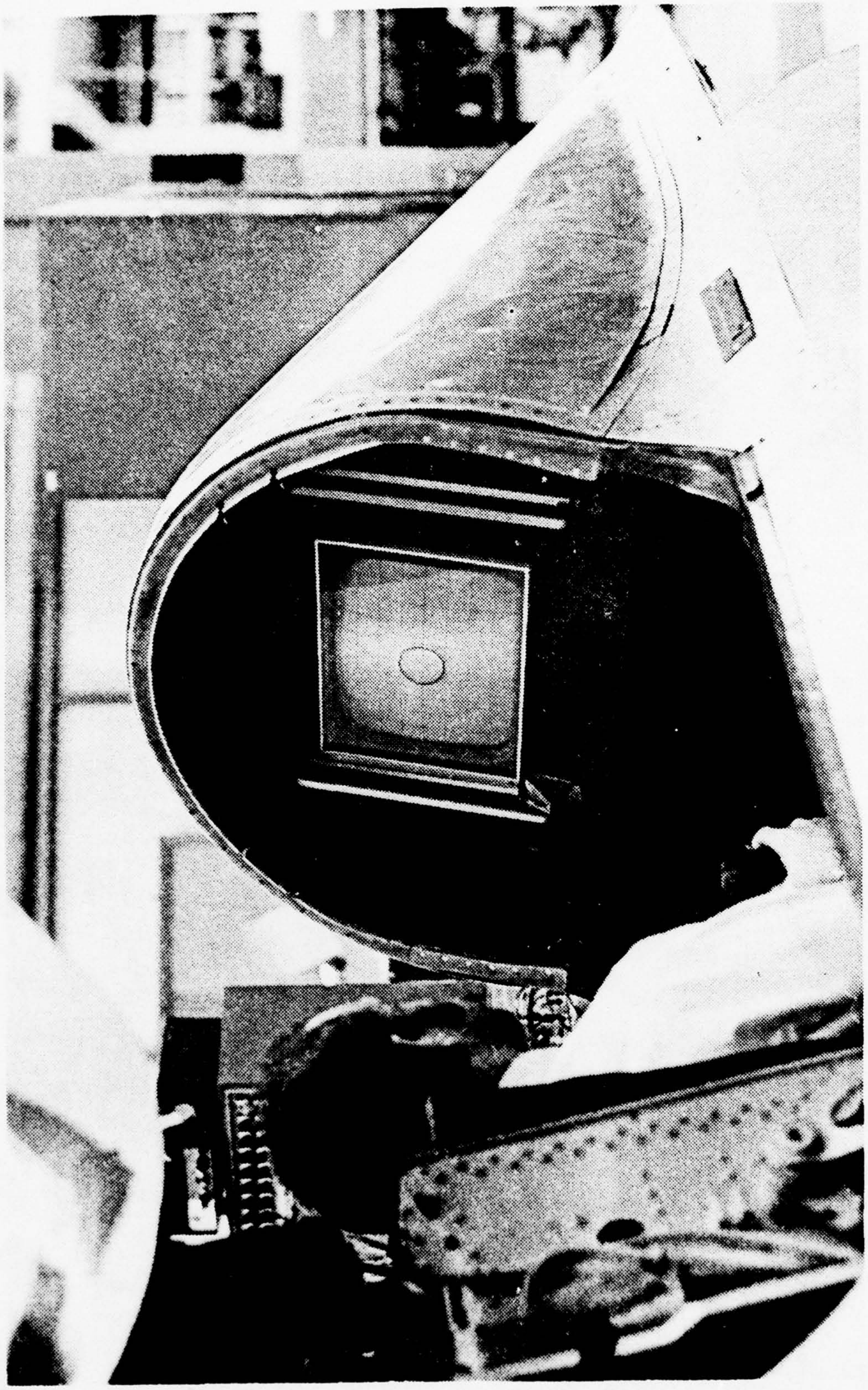


Figure 17 - MOCK COCKPIT

ENERGY MANAGEMENT DISPLAY	RESPONSE BUTTON
BLINKING LOWER GREEN	MAX EXCESS S. P. (LITTLE FINGER)
BLINKING LOWER GREEN AND UPPER GREEN	
STEADY LOWER GREEN	EXCESS S. P. (RING FINGER)
STEADY LOWER GREEN AND YELLOW	
STEADY LOWER GREEN AND UPPER GREEN	
STEADY LOWER GREEN, YELLOW AND UPPER GREEN	
YELLOW	ZERO S. P. (MIDDLE FINGER)
YELLOW AND UPPER GREEN	
STEADY RED AND YELLOW	NEGATIVE S. P. (INDEX FINGER)
STEADY RED	
STEADY RED, YELLOW AND UPPER GREEN	
STEADY RED AND UPPER GREEN	
BLINKING RED	OUT OF ENVELOPE (THUMB)

Figure 18 - GROUPING OF DISPLAY CONFIGURATIONS

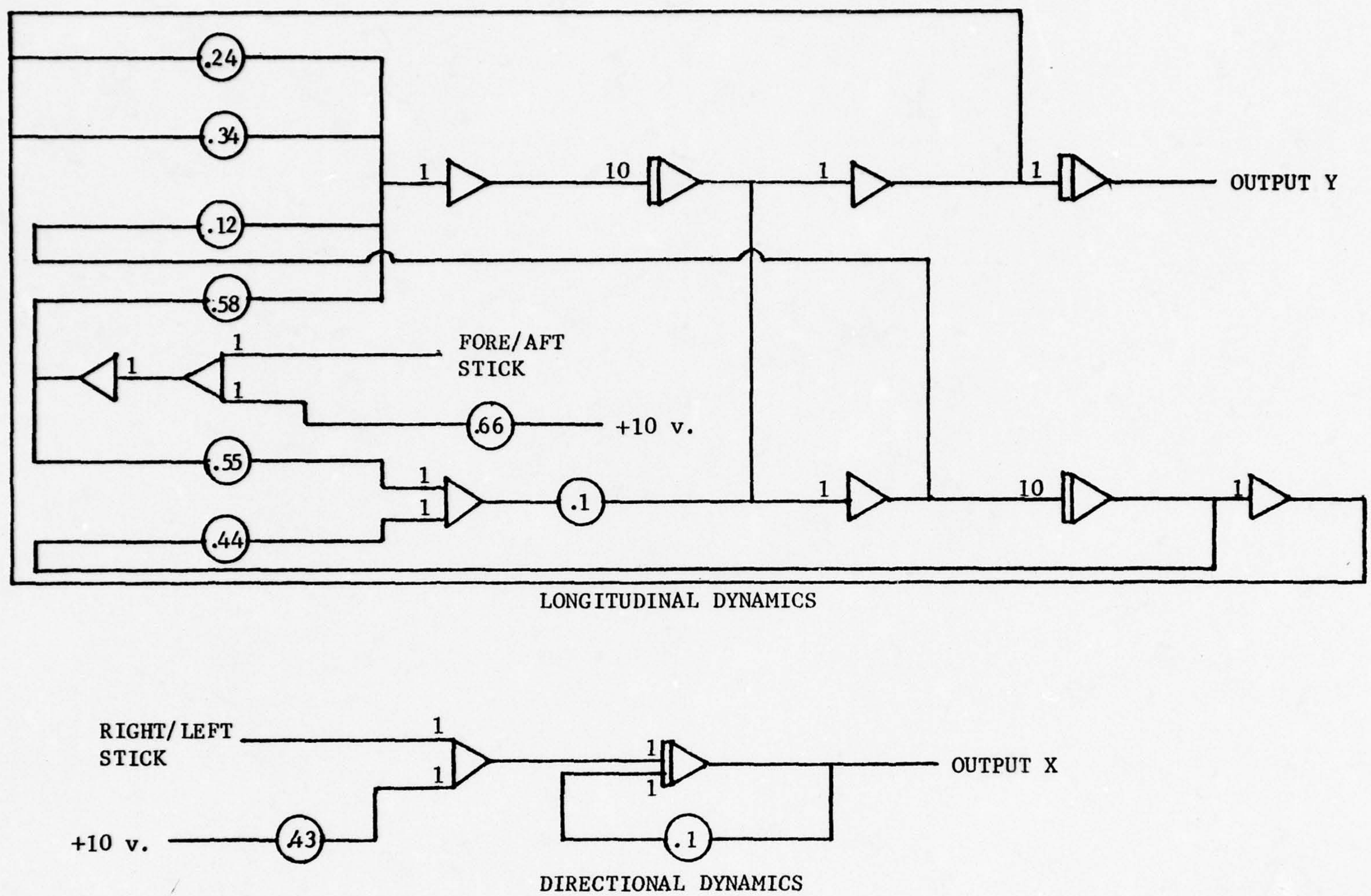


Figure 19 - LONGITUDINAL AND DIRECTIONAL RESPONSE CIRCUITS

A repeatable tracking task was generated by connecting the longitudinal and directional analog outputs of Fig. 19 to the scope and to two of the four available recording channels on the instrumentation tape recorder. The target dot was then flown around the scope screen in a random manner while recording the two outputs simultaneously. Concurrently, a third recording channel was used to record instructions to the operator. These instructions were repeated identically to provide five different tracking tasks of the same length and presentation. These instructions included when to enable and disable the tracking task timer, when to initiate challenges and when to reset the timers. Using the three recording channels in this manner enabled the operator to make a standardized presentation to each subject.

The longitudinal and directional analog outputs were then connected into the timing circuit as shown in Fig. 20. The movement of the dot that is seen by the subject is the sum of the analog outputs and the tracking task from the tape recorder. When this sum is zero, the target dot is in the center of the scope screen. The analog circuitry was provided by Cdr. David Caswell USN, Assistant Professor of Aeronautics Naval Postgraduate School.

The size of the scoring circle is controlled by the voltage input 1N2 to the comparator on the TR-10. The target dot was moved one inch to the right while determining the voltage output of the diode bus. The negative of this voltage was then input to the 1N2 comparator input establishing the one inch radius circular scoring target used in this experiment.

In its initial conception, the secondary task would have used the same hardware and software that was designed

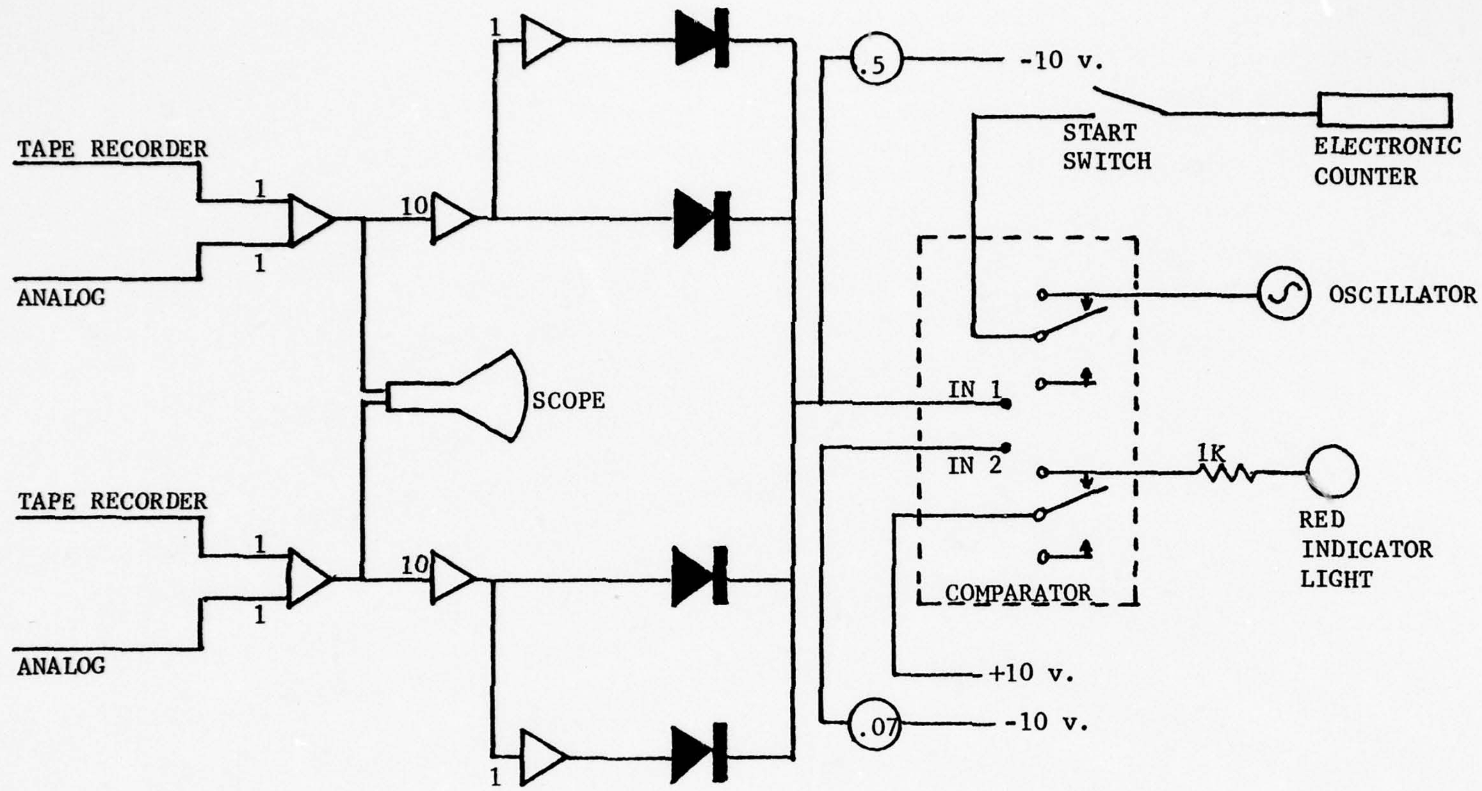


Figure 20 - TIMING CIRCUIT

and built in the EMD design portion of this project. A comparator circuit was built that would trigger the airspeed counter to count up, the G counter to count down and the altitude counter to count down, if the stick were pushed approximately one inch forward. Likewise, it would trigger the airspeed counter to count down, the G counter to count up and the altitude counter to count up, if the stick were pulled back the same distance. It was the intent of this scheme to provide the subject with a continuous EMD that would change in a manner that had direct correlation with the stick movement. A small addition to Computer Program 1 was made that made it possible to freeze the display, initiate the response timer and activate the buzzer when a single challenge button was pushed. The microprocessor was also able to scan the response buttons. When the correct response was made by the subject, the display returned to normal, the timer stopped and the buzzer would be extinguished.

This approach was abandoned for several reasons. The most important reason was that the "out of envelope" region was attained early in every run and remained on a large portion of the time. Attempts were made to provide an equal presentation of all the display configurations by changing the speed and initiation of the counters. No suitable method was found. Instead, this scheme was abandoned and a different approach taken.

It was decided that the microprocessor should be used to control the secondary task completely. A new program (Computer Program 2) was written expressly for this purpose. The program cycles through a loop containing the fourteen possible display configurations. When the challenge button is depressed, one of these display configurations is selected. This selection was considered totally random due to the very high speed of scan of the

microprocessor. Simultaneously, the selected display was illuminated in the cockpit, the response timer was initiated, the buzzer activated and the response buttons scanned for the proper response. If an incorrect response is made, the microprocessor counted and displayed it. This ability to count wrong responses discouraged subjects from trying to "beat the system" by depressing all five buttons at once. When the correct response was detected, the display was extinguished, the timer stopped and the buzzer terminated.

An operator control panel was constructed. This panel included inputs from or outputs to the TR-10, the tape deck, the tracking task timer and oscillator, the stick and the scope. Also mounted on the control panel were the challenge switch, the scoring light switch, the tracking task timer enable switch and the switch that allowed the taped inputs to go to the analog computer.

All digital and analog circuits were maintained electrically separate. It was discovered that the high speed clock incorporated in the microprocessor would rapidly overload the analog computer. Even connecting the microprocessor power supply to the same power source as the analog computer caused an overload.

The final experimental station is shown in Fig. 21. A block diagram of the experiment is shown in Fig. 22.

4. Experimental Procedures

All testing was completed in five sessions. Prior to the first session each subject filled out an information sheet (Appendix D) and listened to a set of taped instructions. The first four sessions were learning

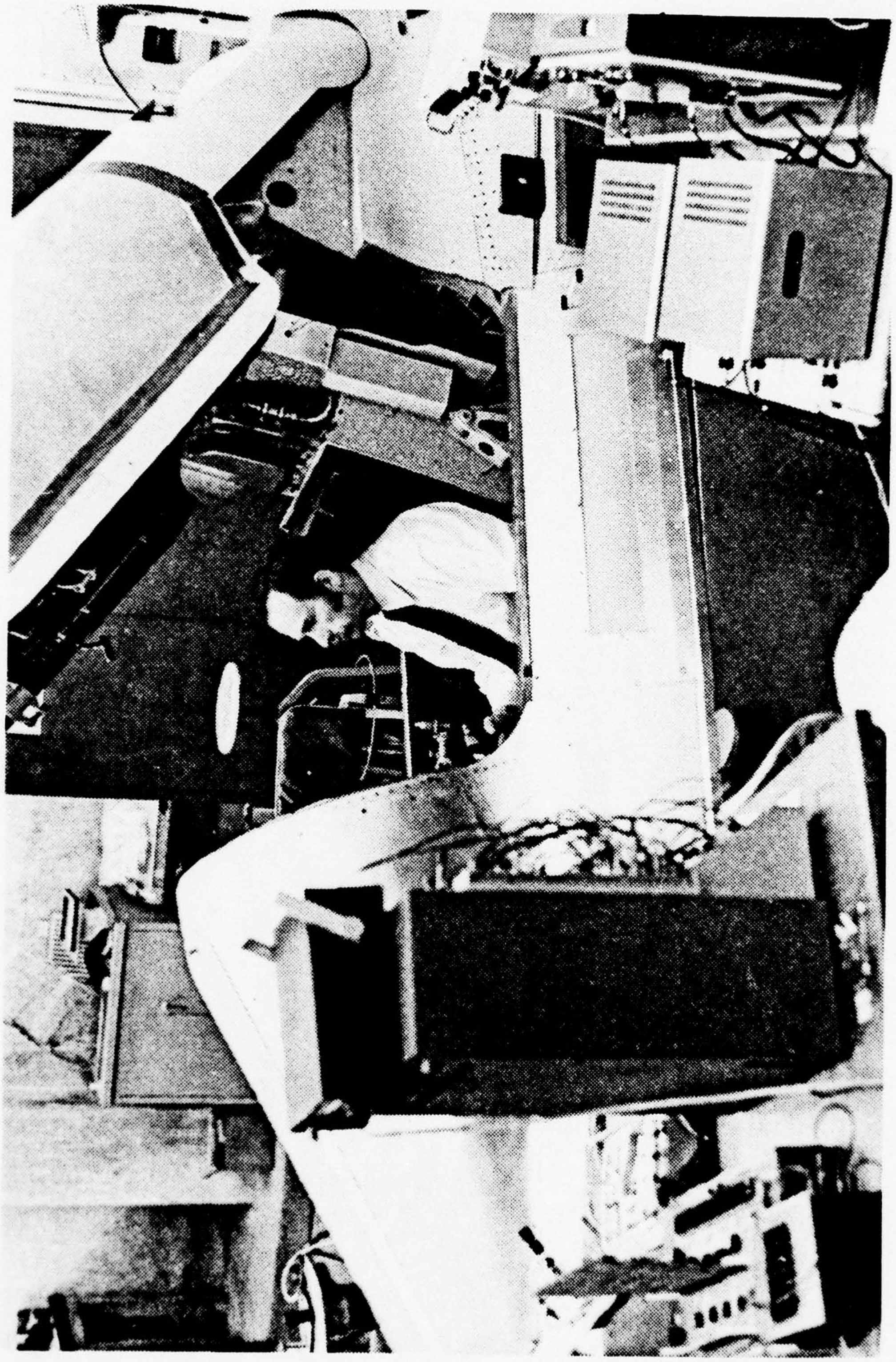


Figure 21 - EXPERIMENTAL TEST STATION

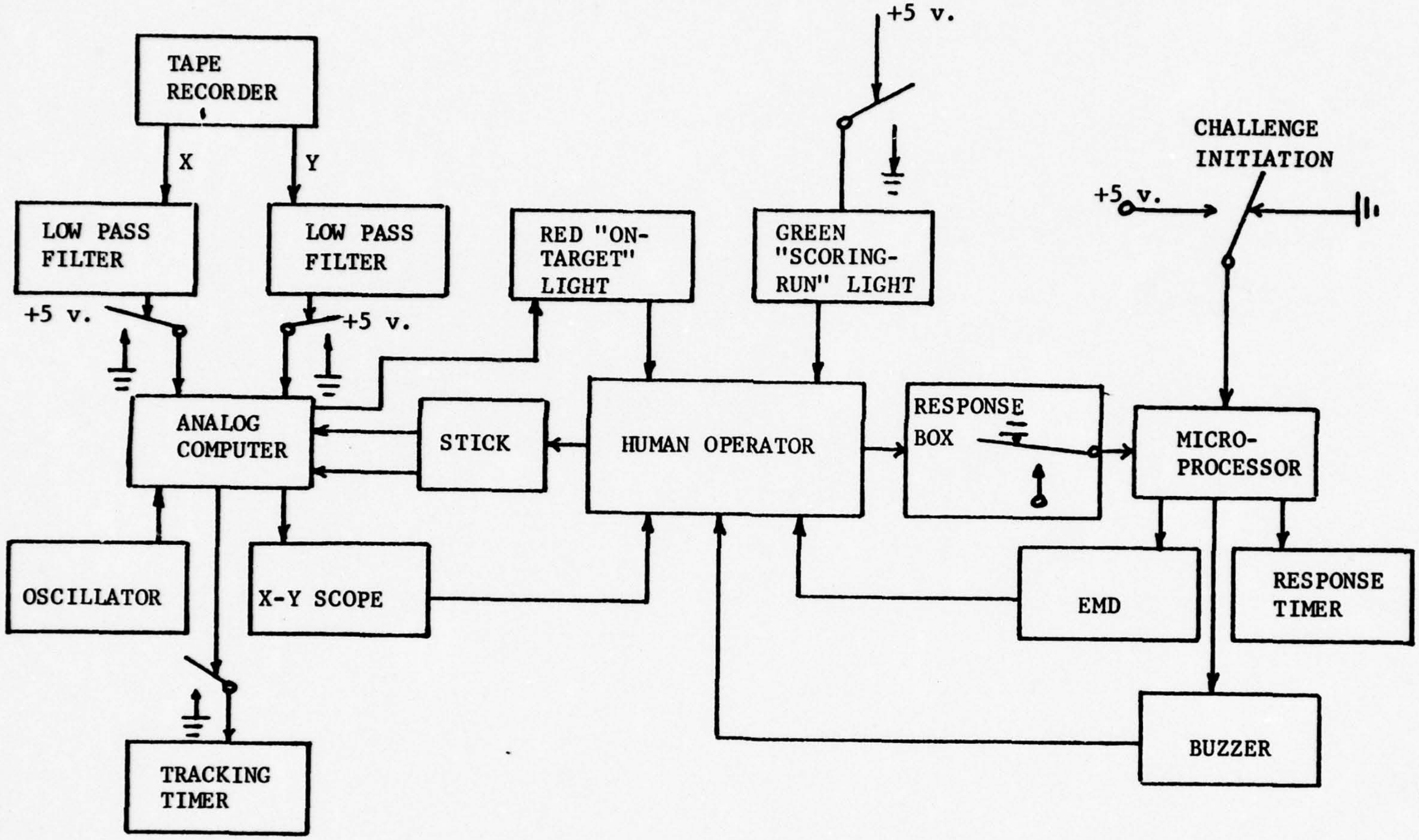


Figure 22 - BLOCK DIAGRAM OF EXPERIMENT

sessions for the tracking task. The fifth session was used for the time sharing presentation.

Each of the first four sessions consisted of five 100-second tracking runs. Each subject was free to adjust the target dot intensity and focus as he liked it. After closing the canopy, the subjects were permitted to fly the dot around with no task, checking the scoring target and allowing their eyes to adapt to the darkness. The dot was frozen by placing the TR-10 to reset and the tape deck activated after the subject indicated that he was ready to begin. The operator recorded the time on target after each of the five runs. The subject had 20 to 30 seconds rest between each run.

Prior to the fifth session, each subject listened to another set of instructions describing the EMD and the time-sharing presentation. Any questions the subjects had were answered. As in the first four sessions, the subjects were permitted to fly the target dot with no task until their eyes were dark adapted. Once indicating that they were ready, the dot was frozen and the tape deck actuated. The subjects performed only the tracking task for the first two runs. The scores of these two runs were checked to insure that they were in the region of their LTS. The third run was an unscored learning session during which the subject was given ten opportunities to respond to a challenge in a time-sharing mode. After rewinding the tape, all five runs were presented in the time-sharing mode. The operator rocorded the time on target, the response time and the number of incorrect responses following each run in the time-sharing mode.

D. EXPERIMENTAL RESULTS

An analysis of variance was done to test for the significance of the differences in performance of the tracking task (A) between the tracking-task-only presentations and the time-sharing presentations. A randomized block factorial 25 (RBF-25) analysis of variance was utilized [Kirk 1969]. This analysis also determines the significance of different levels of difficulty of the 5 tracking runs (B), the significance of differences in subject tracking ability (Blocks) and the significance of interactions between A and B. The results of this analysis are shown in Fig. 23.

Of all challenges initiated, 77.1 percent were answered correctly on the first response. Each subject averaged 1.63 errors per run. The subjects averaged 1.27 seconds to respond to a challenge without an error. 2.03 seconds were required to reach the correct response when one or more incorrect responses were made. Overall, the subjects averaged 1.44 seconds to make a correct response.

E. DISCUSSION OF EXPERIMENTAL RESULTS

The statistical hypothesis was accepted as true. The analysis of variance indicated that the difference in the performance of the tracking task in the time-sharing mode and in the non-time-sharing mode (A) was insignificant (less than .75 probability of being significant).

The analysis also indicated that there was less than a .01 level of significance (more than .99 probability of being significant) that the subjects had different tracking task abilities. This result was expected due to the wide range of flight experience of the subjects. Further, the

SOURCE OF VARIANCE	SUM	DEGREES OF FREEDOM	MEAN SQUARE	F
BLOCKS	7019.2	17	412.9	29.58 **
TREATMENTS	2787.6	9		
A	12.18	1	12.18	.872
B	2661.9	4	665.5	47.7 **
AB	113.0	4	28.25	2.02
RESIDUE	2135.4	153	13.96	
TOTAL	11941.6	179		
** $p < .01$				

Figure 23 - RANDOMIZED BLOCK FACTORIAL ANALYSIS OF VARIANCE SUMMARY TABLE

analysis indicated that the siginficance level of the difference in difficulty of the tasks was less than .01. This result was also predictable due to the range in run averages from 51.1 seconds (run 2) to 63.1 seconds (run 1).

The analysis indicated that the AB interaction (the significance of the runs in B due to the level of A) was insignificant. Finding the AB interaction insignificant permitted the acceptance of the statistical hypothesis (A) without further investigation.

The number of response errors made by the subjects was considered insignificant with respect to acceptance of the statistical hypothesis. The average time to a correct response when an error was made was 2.03 seconds as compared with 1.27 seconds when no errors were made. It was considered by the experimenter that the much longer response time when one or more errors were made was reflected in a degraded tracking task score in the time-sharing mode.

Many of the errors made were attributed to several display deficiencies and ambiguities. A large majority of the subjects commented that the upper green row was extremely confusing and ambigious. The subjects stated that in many cases their initial response to an upper green row was the same as if the lower green row was illuminated. Many of the subjects also felt that the blink rate (1.25 Hz.) of the red and lower green rows was too slow. They often responded as though the row was steady before it would blink. The probability of a display being illuminated that contained one of the two deficiencies most mentioned was .64 each time a challenge was initiated.

The overall average of 1.44 seconds to reach the correct response was considered totally acceptable for several reasons. The first was that the EMD was not illuminated

continuously as it would be if actually employed. When the subject was challenged, he had absolutely no idea what the previous display state was. The second was that in this experimental environment the subject had no indication of what his airspeed, altitude, G or attitude was. If the EMD were actually employed, the pilot would know these values approximately and would be anticipating a certain range of display configurations. The third reason was that the pilot would not be required to select and depress a button corresponding to his energy state during an ACM engagement.

V. CONCLUSIONS

Additional research should be conducted to determine the feasibility of a color-coded, peripheral vision EMD. The skill and task analysis indicated that a device to aid the pilot to maneuver the aircraft to its aerodynamic limits might be useful, but that such a device might be ineffective due to the high level of sensory saturation during ACM. Definite derivative benefits of an EMD were seen to exist in future generation aircraft, pilot training and aviation safety. Interpretation and response to the proposed EMD have been shown to cause no significant degradation in the ability of a pilot to perform a tracking task which simulates the mental and visual concentration required during ACM. This demonstrates not only the ease of interpretation and response, but also the rapid learnability of the display configurations.

Initially, two changes should be made to the proposed EMD. The method of displaying corner velocity should be changed or possibly omitted. A possible solution to the ambiguity introduced by using two green rows is to change the upper green row to a white row. This change should be carefully analyzed as a white row might look very much like the yellow row. The second change is that the blink rate of the lower green and the red rows should be increased.

Many of the subjects stated that it was difficult for them to determine the relative position of the rows in their peripheral vision. Several of the subjects mentioned that interpreting the EMD when two or three rows were illuminated simultaneously was much more difficult and time consuming

than if only one row was illuminated. Consideration could be given to reducing the number of rows illuminated simultaneously and the requirement to distinguish relative position.

Following analysis and amendment, the next step should be to mount the modified EMD on a pilot's helmet and conduct in-flight evaluations. An area that should be closely examined during test flights is the effect of increased G's on the pilot's peripheral color vision.

VI. COMPARISON WITH A HED

A joint Navy and Air Force team has designed and built a helmet-mounted energy-management display (HED). The HED is scheduled to be test flown for the first time in March 1977 at NAS Point Mugu in an F-4. This HED projects certain dots of light from a 20x23 matrix (Fig. 24) onto the combiner shown in Fig. 25. These dots are presented in a manner to represent a V-N diagram with a superimposed specific power equal to zero curve and a present position indicator. Although still in development, several objective comparisons can be made between the HED and the EMD proposed in this project.

By virtue of using a 20x23 matrix, the scaling of airspeed and G are limited for the HED. It is desirable to scale airspeed from 0 to 750 KCAS and G from -3 to +8.5 for the F-4. Using the HED, the minimum increment of airspeed is 32.6 KCAS and the minimum increment of G is .575 G. The EMD is arbitrarily scaled using 10 KCAS and .05 G increments. The increment sizes used in the EMD could be decreased by increasing the size of the look-up table.

Several idealizations of the maneuverability diagram were used in the HED design. The HED display format projects a series of dots onto the combiner. To interpret these dots, the pilot visualizes straight lines in the shape of a V-N diagram with a superimposed specific power equal to zero curve. Idealizing the V-N diagram and the specific power equal to zero curve as straight lines is a good approximation in some regimes, but eliminates safe maneuvering regions in other regimes. The EMD utilized the

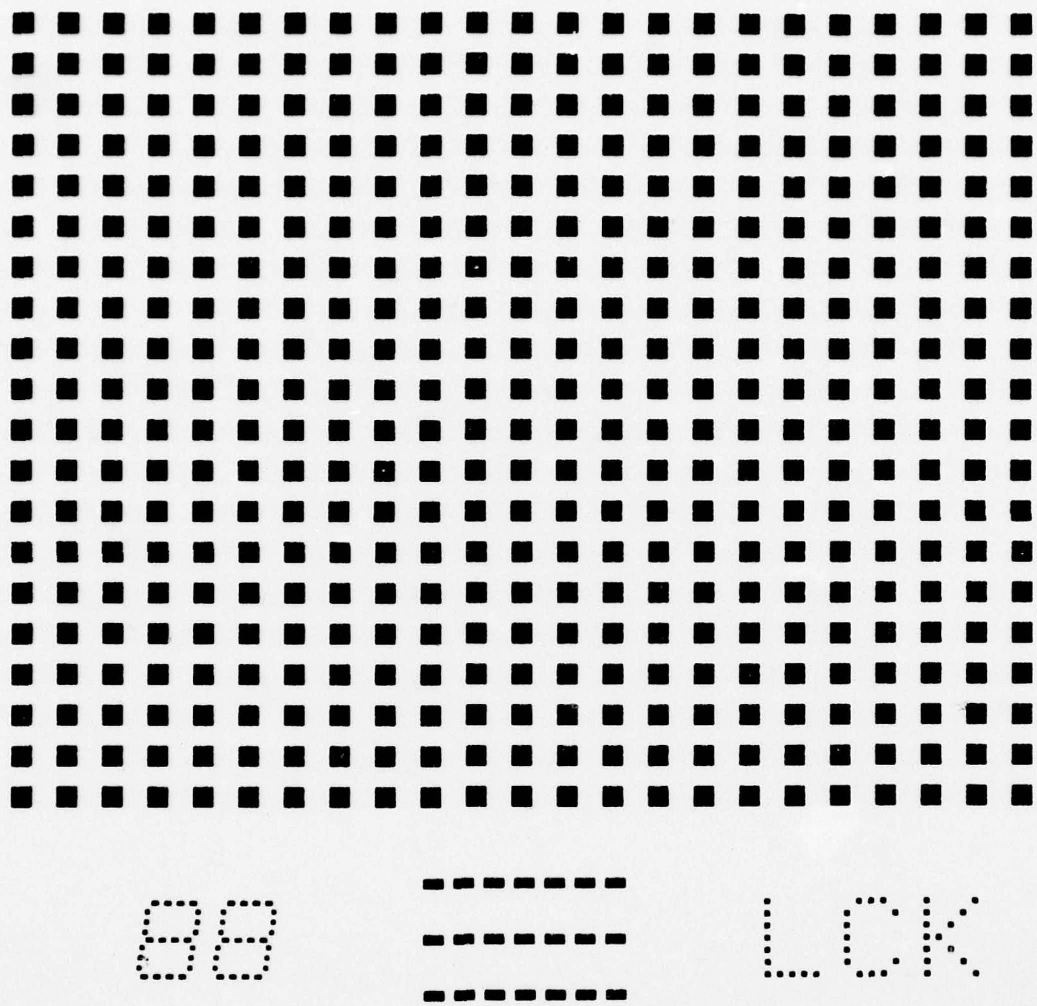


Figure 24 - LED ARRAY FITTED TO PROTOTYPE HMD (MARCONI ELLIOTT AVIONICS)

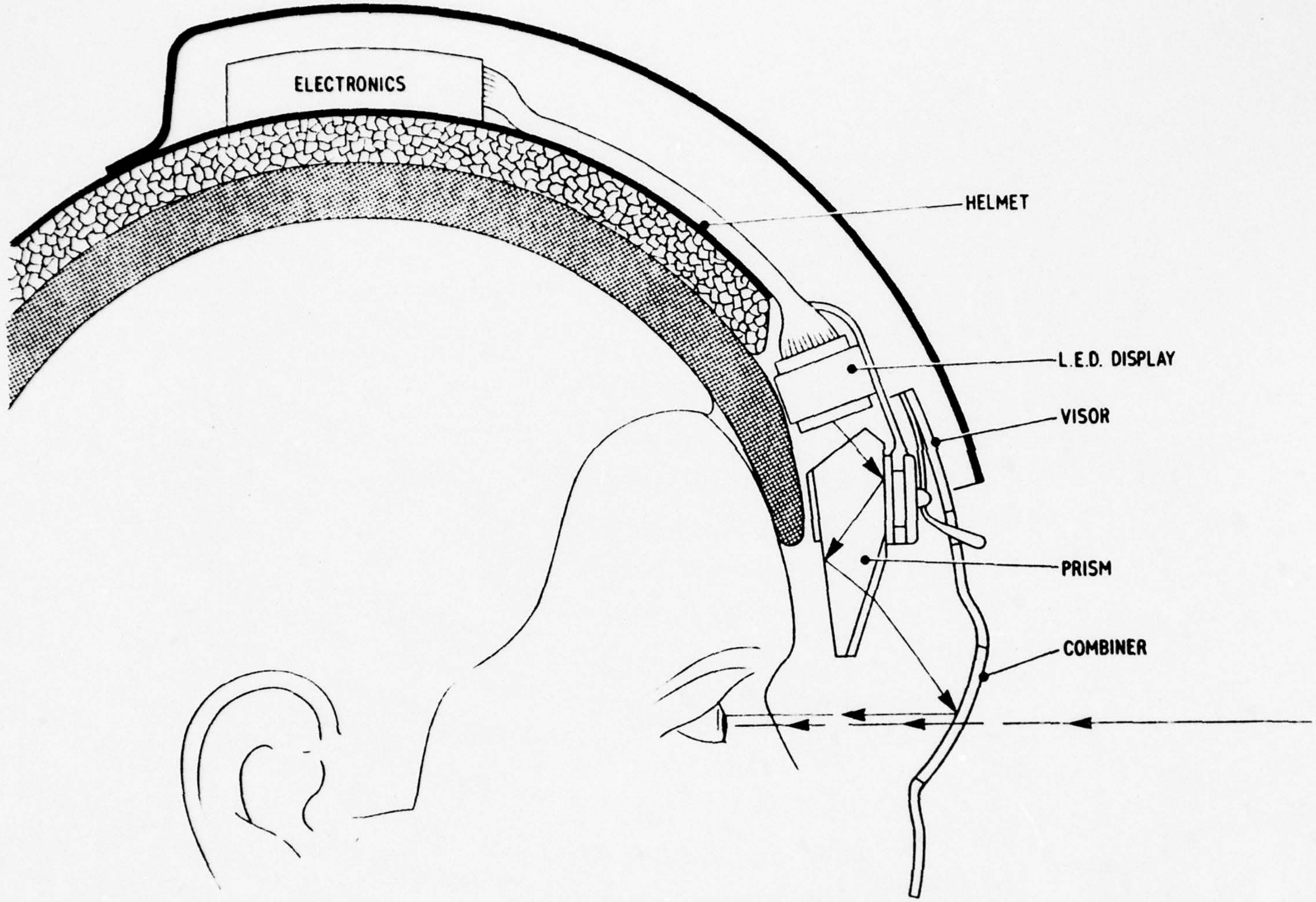


Figure 25 - SCHEMATIC LAYOUT OF PROTOTYPE HMD (MARCONI ELLIOTT AVIONICS)

the maneuverability diagrams (Fig. 7) without any idealizations or alterations.

The HED effectively represents the current aircraft speed with respect to corner velocity. As proposed, the EMD would only provide an indication of being above or below corner velocity.

The HED utilizes only red light in the pilot's primary vision region vice the tri-colored lights in the pilot's peripheral vision region used in the EMD. A display presentation for ACM in the pilot's primary vision region has proven its effectiveness under increased G in the reticle cf the VTAS system. The usefulness of a multi-colored display in the peripheral vision region under increased G should be investigated before operationally deploying a version of the proposed EMD.

APPENDIX A

TAPED INSTRUCTIONS FOR TEST SUBJECTS

INSTRUCTIONS FOR TRACKING TASK ONLY

You are now seated in a cockpit mock-up designed to examine the feasibility and utility of an energy management display for air combat maneuvering (ACM). For the first group of test runs you need only be familiar with the operation of the stick, the scope and its adjustment knobs, the two lights at the base of the scope (one red and one green) and the operation of the canopy. As you listen to these instructions, orient yourself in the cockpit in preparation for the test runs. You will be asked to close the canopy during a later part of these instructions in order that your eyes might adjust to the darkness.

The stick operates as a normal aircraft stick controlling the dot on the scope screen. Pushing the stick forward causes the dot to move down the screen and pulling it back causes the dot to move up the screen. Right stick causes the dot to move to the right and left stick to the left. The object of the tracking task will be to maintian the dot within the one inch circle depicted in the center of the scope screen.

The two knobs at the base of the scope screen are the intensity and focus adjustments for the dot. The knob on the left controls the intensity, decreasing in a counter

clockwise direction. You will want to use this adjustment as the canopy closes and as your eyes become dark adapted. The knob on the right controls the dot focus. After initially focusing the dot, you should have no further need for this adjustment. The lighted red button at the far left base of the scope screen is the scope power. Please do not depress this button at any time.

The canopy control switch is on the left bulkhead just above the console. Please lower the canopy at this time. You need not lock the canopy in the down position. Should an emergercy of any kind occur and you desire to exit the cockpit, raise the canopy and exit the right side of the cockpit, If you are not able to raise the canopy, pound on the left side of the canopy with your fist and the operator will open the canopy and then secure all electrical power.

The red light at the right base of the scope screen will be illuminated only when the target dot is within the one inch circular scoring grid in the center of the screen. The green light at the left base of the scope is used as an indicator to you that a scoring run is in progress. When this light is not illuminated, please do not move the stick.

The first four test sessions will consist of accomplishing the tracking task only. This task is being used to simulate keeping sight of an enemy aircraft during an ACM engagement. Each of the first four sessions will consist of five 100 second tracking runs interrupted with a short period of rest between each.

When the green light illuminates, you may center the dot with the stick. Continue to maintain the dot within the scoring grid to the very best of your ability as long as the green light remains illuminated. Your score will be the percentage of the total scoring run that you are able to

maintain the dot within the scoring grid. When the green light goes out, please release the stick. You will have several seconds rest prior to the next run.

If you have any questions, please ask them now. If not, your first scoring run will begin shortly.

INSTRUCTIONS PRIOR TO COMBINED TASKING

This is your fifth and final session in this test sequence. You will be asked to perform an additional task during this session. Your objective is to maintain the dot within the scoring grid to the best of your ability while responding to the energy management display (EMD).

The EMD is based on color coding various regions of the maneuverability diagram (Fig. 8). The maneuverability diagram is the positive G portion of the VN diagram with specific power curves super imposed. Positive specific power, measured in feet per second, is a measure of the ability to convert excess power into a rate of climb or a level acceleration while maintaining the current G loading. Negative specific power indicates that in order to maintain the current aircraft G loading, the aircraft will either decel in level flight or maintain airspeed and descend. Zero specific power indicates that airspeed and G loading may be maintained at a constant altitude. In most cases, zero specific power is the minimum sustained turning radius and maximum sustained turning rate for any given airspeed.

The maneuverability diagram has been paritioned and color coded into seven regions based on zero specific power (Fig. 9). These regions are displayed using the four rows of colored lights above the scope screen. The lower row of green lights is used to represent positive specific power.

If it blinks green, the aircraft is between +.5G and -.5G. This is the region of maximum excess specific power. The lower green row alone indicates a high level of excess specific power while the lower green and yellow rows together display a lesser level of excess power. The yellow row alone represents the region immediately surrounding the zero specific power curve. The yellow and red rows indicate a low level of negative specific power while the red row alone indicates a high level of negative specific power. The red row will blink alone if any of the basic VN diagram limits are exceeded. The upper green row will be illuminated if corner velocity has been attained and will be out if not. None of your responses will be associated directly with the upper green row.

Directly associated with the EMD for this test is a box with five buttons on it on the left console. Study this box and its correlation to the EMD memorizing the position of the buttons. The 'max. excess S. P.' button is associated with the blinking lower green row, the 'excess S. P.' button with the solid lower green row or the solid lower green and the yellow rows together, the 'zero S. P.' button with the yellow row alone, the 'negative S. P.' button with the yellow and red rows together or the red row alone and the 'out of envelope' button with the blinking red row.

Although this EMD was designed and built using data for an F-4J, your ability to perform the tasks is not related to your knowledge or lack of, of the F-4. As in the first four sessions, the tracking task is being used to simulate keeping sight of an enemy aircraft during an ACM engagement. In addition to performing this task you will also be asked to interpret and respond to the EMD. The EMD is being controlled in a totally random manner by a microprecessor. neither the position of the stick nor its motion have any impact at all on the display that is presented for this set

of tests. In reality, inputs of airspeed, altitude and G would be the controlling inputs to the microprocessor. Your objectives are to maintain the dot in the center and respond to the EMD when challenged. Do not attempt to fly to or maintain any given level of specific power as you have absolutely no control over it in this experiment.

Please close the canopy at this time in order tc dark adapt your eyes.

As in the first four sessions, you should not move the stick until the green light is illuminated. When it is illuminated and the entire time it is on, you should do your very best to maintain the dot within the scoring grid. In this session, while performing the tracking task, you will be challenged with a buzzer several times throughout the scoring runs. When the buzzer is initiated, the EMD will illuminate in one of the previously described states and a timer will be started. As soon as you hear this buzzer, you should depress the button corresponding to the specific power level depicted by the EMD. When the correct button is depressed, the tone will be terminated, the display will be extinguished and the timer will stop. Do not depress more than one button at a time. your score will based on the percentage of the total scoring run that you maintain the dot within the scoring grid and the time it takes you to respond correctly when challenged. The time to correctly respond will be weighted using the number of incorrect responses. If you lose the dot off of the side or the top of the screen, please notify the operator immediately and he will restore the dot onto the screen.

It is not expected that you will need to look at the response buttons during the scoring runs. Prior to each scoring run, you should place your left hand on the response box with one finger on each button so that there is no

problem finding the button you want when you are challenged.

If you have any questions, please ask them now. If not, the first of two tracking task only runs will begin shortly. If your score on these two runs falls within the range of your learned tracking score average established during the first four sessions, then the third run will consist of the 100 second tracking task with 10 challenges. This third run is an unscored practice run for you. Following the practice run, the first of five dual tasked scoring runs will begin.

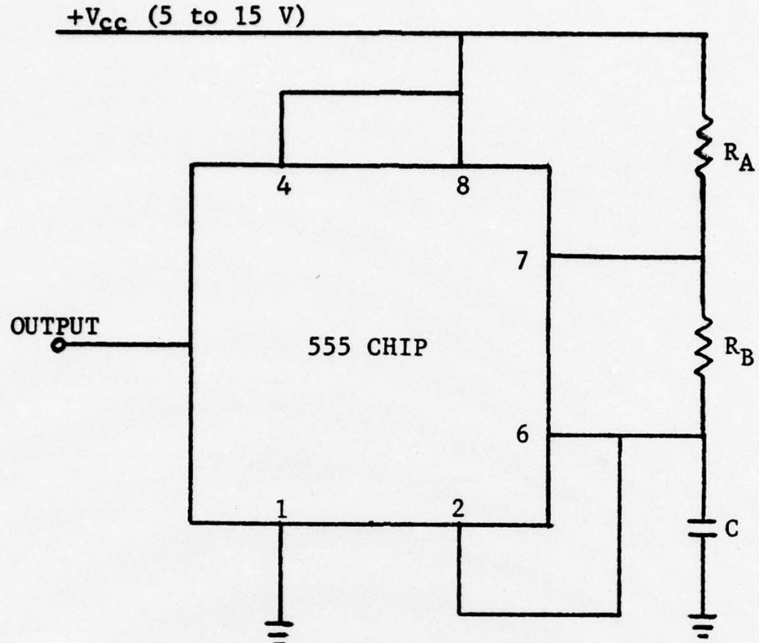
Please focus the target dot to the same shape and size that you used during the first four learning sessions.

APPENDIX B

LIST OF EQUIPMENT

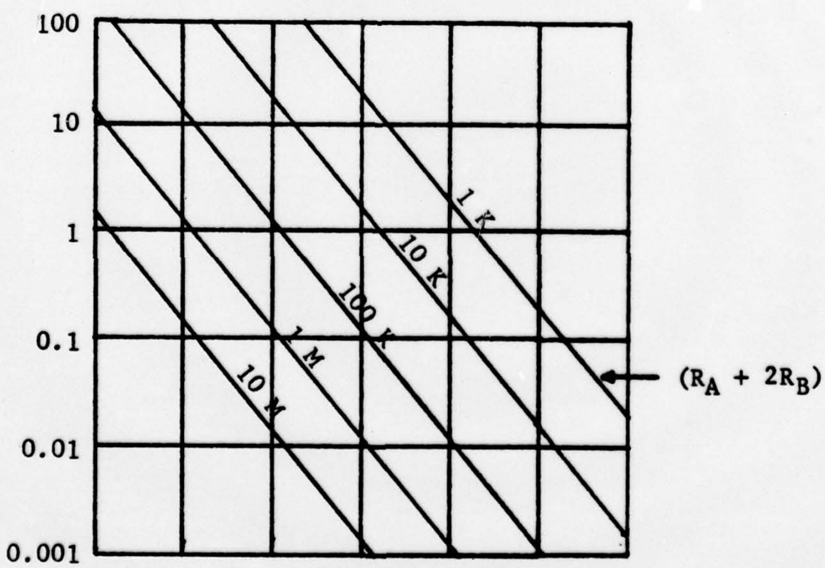
1. Dynasciences Counter, CP-929/USM-245A.
2. Hewlett Packard Wide Range Oscillator, Model 200CD.
3. Hewlett Packard Electronic Counter, Model 521C.
4. Two Krohn-Hite Ultra-Low Frequency Band Pass Filters, Model 330-M.
5. Midwestern Instruments Instrumentation Recorder/Reproducer, Model 434.
6. Pace Analog Computer, Model TR-10.
7. Intel System Interface and Control Module (8008 microprocessor), Model MCB8-10.
8. Hewlett Packard X-Y Scope, Model 1300A.

APPENDIX C



SIGNETICS p. 6-52

FREE RUNNING FREQUENCY
vs R_A, R_B AND C



FREE RUNNING FREQUENCY
SIGNETICS p. 6-52

APPENDIX D

TEST SUBJECT INFORMATION

1. Name________________________________Age___________

2. Flight experience

   A. The four aircraft in which you have the most hours

	Aircraft	Hours
1		
2		
3		
4		

   B. Total flight hours__________________

   C. When did you last fly operationally_________________

3. Do you have any combat experience? Yes No

4. Data

   A. First 4 sessions

	Session 1	Session 2	Session 3	Session 4	LTS
Run 1					
Run 2					
Run 3					
Run 4					
Run 5					

   B. Fifth session

	Run 1	Run 2	Run 3	Run 4	Run 5
Chg 1					
Chg 2					
Chg 3					
Chg 4					
Chg 5					
Total					
Avg.					
Errors					
Time					
Delta					

VII. COMPUTER PROGRAM 1

```
/*DECLARATIONS AND LOOK-UP TABLE--LOOK-UP TABLE CALLED */
/*G$STO AND CONSISTS OF CODED VALUES FOR STRUCTURAL G */
/*OR 20 UNITS AOA AND G VALUES FOR P(S)=0.  THE TABLE IS */
/*ORGANIZED BY ALTITUDE (SEA LEVEL, 10K, 20K AND 30K) AT */
/*10 KT INTERVALS FROM 100 TO 750 KCAS. */

DECLARE (ALTITUDE, AIRSPEED,G,CORNER$VELOCITY,MEMORY$SELECT,
 KEY,STRUCTURAL$G,NEUTRAL$G,A,B,C,D,LIGHT,MULTIPLEX,LEK,CHECK,
 TONE,RESP) BYTE;
DECLARE G$STO DATA (85,79,87,83,91,87,93,89,95,93,99,95,103,99,
 105,103,107,107,111,111,115,113,117,117,121,119,125,123,127,127,
 131,131,133,133,137,137,139,139,143,143,147,147,151,151,155,153,
 161,157,165,159,171,163,177,167,183,171,189,173,195,177,201,181,
 209,183,219,187,229,189,245,193,245,197,245,201,245,203,245,207,
 243,211,241,213,239,217,237,221,235,223,233,227,231,231,229,235,
 227,237,225,241,223,243,223,247,221,243,219,237,217,233,215,227,
 213,221,211,215,209,207,207,199,207,191,205,181,205,169,205,157,
 205,143,205,127,205,109,87,113,87,113,89,115,91,115,93,117,
 95,117,97,119,99,119,103,121,105,123,107,123,111,125,113,127,
 117,129,121,129,123,131,127,133,131,135,135,137,139,139,143,141,
 147,145,151,147,155,149,161,153,167,155,171,157,177,161,181,163,
 187,167,191,169,197,173,203,175,209,177,215,181,219,183,227,187,
 231,189,229,193,227,195,225,197,223,199,221,199,219,199,217,199,
 213,197,211,195,209,195,207,193,205,191,205,189,205,187,205,185,
 205,183,205,181,205,179,205,177,205,175,205,171,205,169,205,165,
 205,163,205,159,205,155,205,151,205,145,85,93,87,95,89,97,91,97,
 93,99,95,101,97,103,99,105,101,107,105,109,107,111,109,113,113,115,
 115,117,117,119,121,121,125,123,129,125,133,127,135,129,141,133,
 143,135,147,137,153,141,157,143,163,145,169,147,173,151,179,153,
 185,155,189,157,195,161,201,161,207,163,213,165,217,165,215,165,
 213,165,209,165,207,165,205,163,205,163,205,163,205,163,205,163,
 205,161,205,161,205,159,205,159,205,159,205,157,205,157,205,155,
 205,155,205,155,205,153,205,151,205,151,205,149,205,147,205,145,
 205,143,205,139,205,137,205,133,205,129,85,89,87,91,89,93,
 89,93,91,95,93,97,97,97,99,99,101,101,103,103,107,105,109,107,
 113,109,115,111,117,113,121,115,125,117,127,117,133,121,135,123,
 141,123,145,125,149,127,153,129,159,131,165,133,169,135,173,137,
 179,137,181,137,185,138,189,138,193,138,195,139,197,139,201,139,
 203,139,205,139,205,139,205,140,205,140,205,140,205,140,205,141,
 205,141,205,142,205,141,205,141,205,140,205,140,205,139,205,139,
 205,138,205,137,205,137,205,137,205,136,205,135,205,133,205,133,
 205,131,205,129);
DECLARE LOCATION ADDRESS;
DECLARE  (DISPLAY, TEN, TWENTY,THIRTY, ENERGY,CV,RY,Y,GY,GRE,
      BG,AGRE,CONT,START,VN,SEA$LEVEL,LCW,SCAN,TASK) LABEL;
```

```
   /*INITIALIZE OUTPUT, LEK AND MULTIPLEX */

OUTPUT(1)=0FFH;
 LEK=0;
 MULTIPLEX=01000000B;
 OUTPUT(0)=NOT(00000000);

   /*MAIN PROGRAM LOOP BEGINS WITH "START" */

START:  KEY=0000000B;
      LIGHT=0;

   /*ALTITUDE, AIRSPEED AND G ARE MULTIPLEXED INTO THE */
   /*MICROPROCESSOR USING TWO BITS OF THE SAME OUTPUT PORT USED */
   /*FOR LIGHT CONTROL.  THE TWO MOST SIGNIFICANT BITS OF OUT- */
   /*PUT(1) ARE 0 EACH TIME THIS PORTION OF THE PROGRAM IS */
   /*SCANNED.  THESE TWO BITS ARE INCREMENTED TWICE USING THE */
   /*VARIABLE MULTIPLEX AND INPUTTING A VALUE PRIOR TO AND   */
   /*AFTER EACH INCREMENT. */

      ALTITUDE=INPUT(1);
      LEK=MULTIPLEX+LEK;
      OUTPUT(1)=NOT(LEK);
      AIRSPEED=(INPUT(1) AND 01111111B);

  /*IF THE MOST SIGNIFICANT BIT OF AIRSPEED IS HIGH THEN TONE=10000000B */
  /*AND THE MAIN PROGRAM WILL CONTINUE THRU THIS PASS. */

     TONE=(INPUT(1) AND 80H);

       LEK=MULTIPLEX+LEK;
      OUTPUT(1)=NOT(LEK);
      G=INPUT(1);

   /*IF INPUT AIRSPEED IS GREATER THAN 750 KCAS (AIRCRAFT LIMIT) */
   /*OR LESS THAN 100 KCAS, THEN BLINK THE RED BAR.  */

     IF AIRSPEED>75 OR AIRSPEED<10 THEN LIGHT=00000001B;
                                   ELSE GO TO SEA$LEVEL;
     GO TO DISPLAY;

   /*SCAN THE INPUT ALTITUDE TO DETERMINE CORNER VELOCITY AND */
   /*SELECT PROPER "PAGE" (MEMORY$SELECT) OF THE LOOK-UP TABLE. */

     SEA$LEVEL:  IF ALTITUDE >25 THEN GO TO TEN;
        CORNER$VELOCITY=42;
        MEMORY$SELECT=0;
```

```
        GO TO ENERGY;
    TEN:   IF ALTITUDE >75 THEN GO TO TWENTY;
        CORNER$VELOCITY=43;
        MEMORY$SELECT=1;
        GO TO ENERGY;
    TWENTY:   IF ALTITUDE>125 THEN GO TO THIRTY;
        CORNER$VELOCITY=45;
        MEMORY$SELECT=2;
        GO TO ENERGY;

  /*AT 30K THE F-4 IS LIMITED TO 710 KCAS.   */

    THIRTY:   IF AIRSPEED>71 THEN LIGHT=00000001B;
                             ELSE GO TO CONT;
        GO TO DISPLAY;

  /*IF THE INPUT ALTITUDE IS GREATER THAN 35K, THEN LIGHT */
  /*THE SOLID RED BAR. */

    CONT:   IF ALTITUDE>175 THEN LIGHT =00000010B;
                            ELSE GO TO CV;
        GO TO DISPLAY;
    CV:   CORNER$VELOCITY=40;
        MEMORY$SELECT=3;
        GO TO ENERGY;

  /*IF INPUT AIRSPEED IS GREATER THAN THE CORNER VELOCITY, */
  /*THEN LIGHT THE GREEN BAR ON TOP. */

ENERGY:   IF AIRSPEED>CORNER$VELOCITY THEN KEY=00100000B;

  /*AIRSPEED IS USED TO DETERMINE WHERE WITHIN THE LOOK-   */
  /*UP TABLE THE REQUIRED TWO BYTES OF INFORMATION ARE LOCATED:   */
  /*SHL(AIRSPEED-10)= THE LOCATION ON A GIVEN "PAGE" AND     */
  /*(MEMORY$SELECT*132)= THE APPROPRIATE PAGE OF THE TABLE. */

     LOCATION= (SHL((AIRSPEED-10),1))+(MEMORY$SELECT*132);
    STRUCTURAL$G=G$STO(LOCATION);
    NEUTRAL$G=G$STO(LOCATION+1);

  /*IF THE INPUT G EXCEEDS THE STRUCTURAL G OR -3 G'S, BLINK   */
  /*THE RED BAR.   */

    IF G>= STRUCTURAL$G OR G<= 15 THEN LIGHT=00000001B;
                              ELSE GO TO VN;
    GO TO DISPLAY;

  /*THE VN DIAGRAM IS PARTITIONED INTO SEGMENTS WITH RESPECT   */
```

```
/*TO P(S)=C G FOR THE INPUT AIRSPEEC.  */

VN:  IF NEUTRAL$G>STRUCTURAL$G THEN GC TC LOW;
      A=NEUTRAL$G+SHR((STRUCTURAL$G-NEUTRAL$G),1);
     B=NEUTRAL$G+SHR((STRUCTURAL$G-NEUTRAL$G),3);
 LOW:  C=NEUTRAL$G-(SHR((NEUTRAL$G-75),3));
     D= NEUTRAL$G-(SHR((NEUTRAL$G-75),1));

  /*IF THE INPUT G IS LESS THAN STRUCTURAL G, BUT  */
  /*GREATER THAN THE UPPER "1/2 POINT," THEN LIGFT THE SCLID  */
  /*REC EAR.  */

    IF G<STRUCTURAL$G AND G>=A THEN LIGHT=00000010B;
                                ELSE GC TO RY;
    GC TO DISPLAY;

  /*IF TFE INPUT G IS LESS THAN THE "UPPER 1/2  */
  /*PCINT" AND GREATER THAN THE "UPPER 1/8TH PCINT," LIGHT  */
  /*TFE REC AND AMBER BARS.  */

 RY:  IF G<A AND G>=B THEN LIGHT =00000110B;
                      ELSE GO TO Y;
    GC TC DISPLAY;

  /*IF THE INPUT G IS BETWEEN THE "1/8TH POINTS" AROUNC TFE  */
  /*P(S)=0 G, LIGHT THE AMBER BAR.  */

 Y:  IF G<B AND G>C THEN LIGHT=00000100B;
                    ELSE GO TO GY;
    GC TO DISPLAY;

  /*IF THE INPUT G IS LESS THAN THE LCWER "1/8TF PCINT" AND  */
  /*GREATER THAN THE LOWER "1/2 POINT, THEN LIGFT THE LCWER  */
  /*GREEN AND AMBER BARS.  */

 GY:  IF G<=C AND G>D THEN LIGHT =000C1100B;
                      ELSE GO TO GRE;
    GC TO DISPLAY;

  /*IF TFE INPUT G IS LESS THAN THE LOWER "1/2 PCINT" AND GREATER */
  /*THAN +.5 G, THEN LIGHT THE LOWER GREEN BAR.  */

 GRE:  IF G<=D AND G>85 THEN LIGHT = 00001000B;
                        ELSE GO TO BG;
    GC TC DISPLAY;

  /*IF THE INPUT G IS BETWEEN +.5 G ANC -.5 G, TFEN BLINK THE  */
  /*LOWER GREEN BAR.  */
```

```
BG:   IF G<=85 AND G>=65 THEN LIGHT=00010000B;
                         ELSE GO TO AGRE;
    GO TO DISPLAY;

  /*IF THE INPUT G IS BETWEEN -.5 G AND -3.0 G, THEN LIGHT THE  */
  /*SOLID GREEN BAR.  */

AGRE:   IF G<65 AND G>15 THEN LIGHT =00001000B;
                          ELSE GO TO DISPLAY;

  /*USING "LIGHT AND KEY," A VALUE IS DETERMINED FOR LEK AND  */
  /*THUS OUTPUT(1).  */

DISPLAY:   IF LIGHT=00000001B THEN LEK=00000001B;
               ELSE LEK=LIGHT + KEY;
  OUTPUT(1)=NOT(LEK);

  /*IF TONE IS 80H, THEN SCAN FOR THE PROPER RESPONSE.  */
  /*IF TONE IS NOT 80H, THEN CONTINUE THE NORMAL PROGRAM. */

IF TONE=80H THEN GO TO TASK;
            ELSE GO TO START;

  /*THE LOOP TASK WILL INITIATE THE TONE, START THE RESPONSE TIMER AND */
  /*SCAN FOR THE CORRECT RESPONSE.  THE DISPLAY WILL REMAIN CONSTANT */
  /*WHILE IN THIS LOOP REGARDLESS OF CHANGES IN AIRSPEED,ALTITUDE */
  /*OR G.  WHEN THE CORRECT RESPONSE HAS BEEN MADE THE TONE WILL  */
  /*TERMINATE, THE RESPONSE TIMER WILL STOP AND THE DISPLAY */
  /*WILL RETURN TO NORMAL.  */

TASK:   OUTPUT(0)=NOT(00000011B);
     IF LIGHT=00000001B THEN RESP=00000001B;
     IF LIGHT=00000010B OR LIGHT=00000110B THEN RESP=00000010B;
     IF LIGHT=00000100B THEN RESP=00000100B;
     IF LIGHT=00001100B OR LIGHT=00001000B THEN RESP=00001000B;
     IF LIGHT=00010000B THEN RESP=00010000B;

SCAN:   CHECK=INPUT(0);
     IF CHECK=RESP THEN OUTPUT(0)=NOT(00000000B);
                   ELSE GO TO SCAN;
    GO TO START;
EOF
```

VIII. COMPUTER PROGRAM 2

```
/* THIS PROGRAM WILL USE ONLY 1 INPUT PORT ANC TWO OUTPUT PORTS. */
/* 5 BITS OF THE INPUT PORT WILL BE USED FOR THE SECONDARY TASK */
/* SCCRING AND 1 BIT WILL BE USED TO KEY THE PRCPER SEQUENCES */
/* ANC RANCOMLY SELECT THE DISPLAY TC BE TESTED.  SIX BITS OF */
/* CNE OUTPUT PORT WILL BE USED TO CCNTROL THE CISPLAY AND   */
/* 1 BIT WILL BE USED TO CONTROL THE SECONDARY TASK TIMER ANC THE */
/*TONE.  THE SECOND OUTPUT PORT WILL OUTPUT THE NUMBER CF */
/*INCCRRECT RESPCNSES.*/

DECLARE (LIGHT,RESP,CHECK,KEY,COMP,INCCRR,XY) BYTE;
DECLARE (RANDOM,TASKING,SCAN,OPT$A,OPT$B,OPT$C,OPT$D,OPT$E,CPT$F,
     OPT$G,OPT$H,OPT$I,OPT$J,OPT$K,OPT$L,OPT$M,OPT$N,WRONG) LABEL;

  /* START THE RANDOM SELECTION MAINTIANING NO CISPLAY PRESENTATION */

RANCCM:  OUTPUT(1)=NOT(00000000B);
         CUTPUT(0)=NOT(00000000B);

  /* VARIABLE CHECK USED TO SEE IF SUBJECT HAS BEEN CHALLENGED. */

   CPT$A:  CHECK=(INPUT(1) AND 20H);
     IF CHECK=20H THEN LIGHT=01010000B;
                     ELSE GO TO OPT$B;
        GO TO TASKING;
   OPT$B:  CHECK=(INPUT(1) AND 20H);
     IF CHECK=20H THEN LIGHT=01001000B;
                   ELSE GC TO OPT$C;
        GO TO TASKING;
   CPT$C:  CHECK=(INPUT(1) AND 20H);
     IF CHECK=20H THEN LIGHT=01001100B;
                   ELSE GC TO OPT$D;
        GC TO TASKING;
   OPT$D:  CHECK=(INPUT(1) AND 20H);
     IF CHECK=20H THEN LIGHT=01000100B;
                    ELSE GO TO OPT$E;
        GO TO TASKING;
   CPT$E:  CHECK=(INPUT(1) AND 20H);
     IF CHECK=20H THEN LIGHT=01000110B;
                   ELSE GC TO CPT$F;
        GO TO TASKING;
   CPT$F:  CHECK=(INPUT(1) AND 20H);
     IF CHECK=20H THEN LIGHT=01000010B;
                   ELSE GC TO OPT$G;
        GO TO TASKING;
   CPT$G:  CHECK=(INPUT(1) AND 20H);
```

```
      IF CHECK=20H THEN LIGHT=01000001B;
                        ELSE GO TO OPT$H;
         GO TO TASKING;
    OPT$H:  CHECK=(INPUT(1) AND 20H);
      IF CHECK=20H THEN LIGHT=01110000B;
                        ELSE GO TO OPT$I;

         GO TO TASKING;
    OPT$I:  CHECK=(INPUT(1) AND 20H);
      IF CHECK=20H THEN LIGHT=01101000B;
                          ELSE GO TO OPT$J;
         GO TO TASKING;
    OPT$J:  CHECK=(INPUT(1) AND 20H);
      IF CHECK=20H THEN LIGHT=01101100B;
                        ELSE GO TO OPT$K;
         GO TO TASKING;
    OPT$K:  CHECK=(INPUT(1) AND 20H);
      IF CHECK=20H THEN LIGHT=01100100B;
                        ELSE GO TO OPT$L;
         GO TO TASKING;
    OPT$L:  CHECK=(INPUT(1) AND 20H);
      IF CHECK=20H THEN LIGHT=01100110B;
                        ELSE GO TO OPT$M;
         GO TO TASKING;
    OPT$M:  CHECK=(INPUT(1) AND 20H);
      IF CHECK=20H THEN LIGHT=01100010B;
                        ELSE GO TO OPT$N;
         GO TO TASKING;
    OPT$N:  CHECK=(INPUT(1) AND 20H);
      IF CHECK=20H THEN LIGHT=01000001B;
                        ELSE GO TO OPT$A;
         GO TO TASKING;

   /* THE LOOP TASKING SCANS FOR THE CORRECT RESPONSE TURNING ON */
   /* THE TONE AND TIMER.  WHEN THE CORRECT RESPONSE IS RECOGNIZED */
   /* THE TONE STOPS, THE TIMER STOPS AND NO DISPLAY WILL BE PRESENTED */
   /*UNTIL THE NEXT CHALLENGE.  THE NESTED LOOP 'WRONG' DETERMINES*/
   /*IF AN INCORRECT RESPONSE HAS BEEN MADE AND OUTPUTS IT.  */

 TASKING:  OUTPUT(1)=NOT(LIGHT);
          OUTPUT(0)=NOT(00000000B);
    COMP=(LIGHT AND 00011111B);
      IF COMP=00000001B THEN RESP=00000001B;
      IF COMP=00000010B OR COMP=00000110B THEN RESP=00000010B;
      IF COMP=00000100B THEN RESP=00000100B;
      IF COMP=00001100B OR COMP=00001000B THEN RESP=00001000B;
      IF COMP=00010000B THEN RESP=00010000B;
       INCORR=00000000B;
```

```
     XY=CC000000B;
 SCAN:   KEY=(INPUT(1) AND 00011111B);
      IF KEY=RESP THEN OUTPUT(1)=NOT(00000000B);
                   ELSE GO TC WRONG;
        GC TO OPT$A;
    WRCNG:  IF KEY=XY THEN GO TO SCAN;
            IF KEY=00000000B THEN GO TC SCAN;
            ELSE INCORR=(INCORR+00000001B);
               OUTPUT(0)=NCT(INCORR);
                  XY=KEY;
               GO TO SCAN;
EOF
```

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